THE EFFECTS OF GRAZING ON GRASSLAND IN CENTRAL SASKATCHEWAN

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GRASS LANDS OF CENTRAL SASK. A. J. HEARD

THE EFFECTS OF GRAZING ON GRASSLAND IN CENTRAL SASKATCHEWAN

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INTRODUCTION

The grasslands of the present study area lie in the ecotone between Fescue grasslands to the north and the Canadian mixed prairie to the south. Most of the sites sampled lie within 12 miles of Saskatoon. The grasslands in the south of Saskatchewan have been investigated by Clarke (1930), Clarke and Tisdale (1936, 1945), Clarke _et al._ (1942, 1943), and Coupland (1950), and they have been shown by the identity of the dominant species to be a northward extension of the mixed prairie (Stipa-Bouteloua Association) as classified by Weaver and Clements (1938) and by Clements and Shelford (1939). A study undertaken immediately to the north of Saskatoon has shown the grasslands of that area to be dominated by _Festuca scabrella_ (Coupland and Brayshaw 1953). _F. scabrella_ does not occur as a dominant in mixed prairie, and for that reason these northern grasslands may not be considered a part of the mixed prairie and are here considered as another Association.

The purpose of the present research was to ascertain the ecology of the species and communities of the grasslands within the tension zone between the two grassland Associations. Both relict and grazing disclimax sites were studied. It was considered that a study of these grasslands would yield information on the relationships between the two Associations.

The field work was conducted during the summer of 1952, and greenhouse work and laboratory analysis of samples collected during the summer was completed during the following winter.

A complete list of the plant species referred to is

included (Appendix 1). The nomenclature followed in this paper is that of Hitchcock and Chase (1950) for the grasses, and of Fernald (1950) for other species. Exceptions to this practice are stated.

DESCRIPTION OF THE AREA

Physiography

The prairies of Saskatchewan form part of the Great Plains physiographic region, which in Canada extends from the Laurentian Shield on the east and north to the mountainous Cordilleran region on the west. The physiography of the whole area can be considered to be divided by two eastward-facing escarpments into three physiographic regions: the first, second, and third prairie steppes. Saskatoon lies between the escarpments and in the second prairie steppe. The eastern escarpment, the boundary between the first and second prairie steppe, is approximately 230 miles from Saskatoon. The less well defined western escarpment at its nearest point approaches to within about 40 miles of Saskatoon. West of this lies the third prairie steppe. Elevations in the study area range from 1,546 feet in the Saskatchewan river valley to 1,770 feet. Over the whole second prairie steppe the elevations range from 1,050 feet to 2,000 feet; the topography is principally undulating to gently rolling.

Over most of Central Saskatchewan the surface deposits are of glacial origin. (Mitchell _et al._ 1944; Edmunds 1940).

Deposition on the uplands was mainly in the form of ground moraine. The little information available on the depth of till suggests that in few places is it less than one hundred feet thick. The topography of the area is largely of the knob and kettle type. The lowlands are covered by glacial lacustrine deposits of deep water and deltaic origins. In some areas there has been water and wind working of the clays, silts, and sands, subsequent to deposition.

The southern branch of the Saskatchewan river flows through the area in a northeasterly direction. There is little drainage into the river and little of the precipitation that falls on the area is lost through exterior drainage. In the moraine covered uplands and in all areas of rolling topography there is considerable runoff, the amount depending upon soil texture and the angle of slope. The runoff water, together with that transported by the few streams that run for a short time in the spring, collects in the deeper kettles and is quickly evaporated. Often this water carries excessive amounts of soluble salts leached from the higher land and these salts are deposited in the depressions. The resultant shallow lakes and dry lake bottoms are a characteristic feature of the prairie topography. The local drainage has a considerable influence on soil formation and on soil-plant relationships.

In the lowlands the glacial lacustrine deposits have typically a less rolling form and drainage is more satisfactory.

The underlying geological formations are Cretaceous sands and shales (Mitchell <u>et al.</u> 1944; Edmunds 1940). These sands

and shales are the principal ingredients of the glacial drift, and mixed by ice action with Precambrian granite gneiss and Palaeozoic limestone (which underly the area to the north) they form the parent material of the soils of this area. Where the parent material is predominantly derived from shales the soils are heavy; these heavy soils are fertile where limestone was also present in the rock flour.

Climate

The climate of the area is of the north-temperate continental type and may be classed as cool semi-arid to sub-humid.

Winter temperatures as low as -50 degrees F. are associated with invasions of polar continental air. The ground remains frozen for from four to five months. Milder winter periods result from invasions of polar maritime air from the northern Pacific Ocean. These air currents bring little moisture, and the area is dependent for moisture on tropical maritime air masses which originate in the region of the Gulf of Mexico. Precipitation follows the uplift of the moist maritime air by the dense polar continental air. Most of the precipitation from November to March is as snow (Table 1). The value of the accumulation of moisture in the form of snow during the winter is partially lost to spring growth because of sublimation and because of runoff from the still frozen soil during the spring thaw.

In the summer, high temperatures and clear skies prevail.

TABLE 1

Climatic data. Long term averages and averages for the period 1949 - 1952 at Saskatoon. Data obtained from the Physics Dept., University of Saskatchewan, and from Boughner and Thomas (1948).

	Years Observed	MONTHS J.	F.	M.	A.	M.	J.	Jl.	A.	S.	O.	N.	D.	Yearly Total
PRECIPITATION (inches) * Mean Monthly (underlined where mainly snow).	1914-52	<u>0.87</u>	<u>0.50</u>	<u>0.66</u>	0.72	1.42	2.57	2.41	1.94	1.46	0.88	<u>0.51</u>	<u>0.61</u>	14.55
	1949-52	<u>0.56</u>	<u>0.44</u>	<u>0.66</u>	0.71	1.40	2.36	3.83	1.74	1.00	0.83	<u>0.65</u>	<u>0.55</u>	14.73
Total for April to Sept.	1949-52				(		11.04			)				
EVAPORATION (inches) Mean Monthly	1919-1952					5.16	6.08	6.76	5.49	3.34				
	1949-52					3.82	4.36	4.47	3.93	2.39				
TEMPERATURE (degrees Fah.) Mean of Daily Maximum	1914-52	9	13	27	49	64	71	77	75	63	51	31	16	
	1949-52	-1	13	24	53	66	71	76	76	66	49	32	19	
Mean of Daily Minimum	1914-52	-11	-8	6	26	38	48	52	48	38	27	12	-2	
	1949-52	-19	-7	4	29	39	46	51	50	40	27	15	-5	
SUNSHINE (hours) Mean Daily	1949-52	3.4	4.5	6.3	8.7	9.0	9.1	10.2	9.3	6.9	4.9	3.4	2.7	

* For this computation 10 inches of freshly fallen snow are considered as having an average water equivalent of one inch.

The average yearly precipitation is below 15 inches and evaporation is high, being associated with the instability of the polar continental air and the clear, sunny weather. Because of the clear skies and the dryness of the atmosphere, loss of heat by radiation at night causes wide diurnal fluctuations in temperature. The growing season is shortened by the lack of available moisture in the late summer. In general the frost-free period extends from the last week of May to the second week of September (Table 2).

The mean daily temperature of 42 degrees F. is in common use in temperate climates as an arbitrary figure indicating to some extent a temperature above which most plants will make active growth. In the area of study the mean daily temperatures are above 42 degrees from the last week of April until the first half of October (Currie 1953).

Microclimatic effects are accentuated by the rolling topography, and in the deeper depressions temperature inversion is probably important in determining ecological relationships. Albright and Stoker (1944) working in the Peace River district of Alberta found considerable differences in the minimum temperatures taken in a depression and those taken on the adjacent slopes at an elevation of 134 feet above the floor of the depression. They record a frost-free period of 106 nights for the upper slopes, against a period of only 32 nights in the depression.

TABLE 2

Dates of last Spring frosts and first Autumn frosts.

Year	Last frost	First frost	Frost free days
1949	May 23rd.	Sept. 12th.	113
1950	June 7th.	Aug. 17th.	71
1951	June 5th.	Sept. 23rd.	110
1952	May 31st.	Sept. 22nd.	115

METHODS

Choice of Sites

In the choice of sites for study it was endeavoured to locate relict grassland sites adjacent to grazed native grassland. Where this was possible sampling was undertaken on either side of, and parallel to, the fence line or roadway separating the two sites. These sites are henceforth referred to as paired sites. Single or unpaired sites were also sampled. The legal descriptions of the sites are given (Appendix 2). Considerable care was taken in the choice of sites. Some disturbance of relict grasslands was inevitable because of the practice in this area of fall grazing. Between the end of harvest and the beginning of freeze-up, and sometimes in early spring, horses and some cattle are allowed to range over unfenced land. In no area was this grazing seen to be concentrated as the numbers of cattle involved are not large and the horse population has been small in recent years. The past histories of the sites were obtained to ascertain whether the relict sites had in fact been protected over a long period, and to ascertain the type of grassland management practiced on the grazed sites. It was often possible to obtain information dating from the time of first settlement (Appendix 2). Moss and Campbell (1947) discuss the effect of grazing by the buffalo and the effect of firing on the fescue grasslands of Alberta.

Sites were located on morainic deposits, on lacustrine deposits formerly part of the floor of glacial lake Saskatoon, on soils overlying outwash gravel, and on recent aeolian deposits. The soils of the area have been mapped by Mitchell

et al. (1944). The field maps of that survey were made available for this work and were of great assistance. Soil profiles were cut on all sites and soil texture and colour determined (Appendix 3). Using this information and that obtained from the field maps the sites were grouped according to soil characteristics.

Sampling of Vegetation

The point-transect (point-quadrat) method as devised by Levy and Madden (1933) was used to obtain a measure of the botanical composition of the sites. The method has been reviewed by Crocker and Tiver (1948) and by Hanson (1950). The apparatus consisted essentially of a wooden frame, bored at intervals of 1 dm. to allow the vertical projection of ten long pins through the frame and onto the vegetation. The pins were pushed through the holes and the species hit were recorded. When no vegetation was hit bare ground was recorded. The frame was set down at random; ten projections were made at each setting down. Between 1000 and 1500 projections were recorded for each site. On sites where the total cover by grasses and sedges was low the maximum number of projections was made. The decision as to the number of projections to make was taken after a consideration of the results obtained on similar vegetation by Clarke et al. (1942) and Coupland (1950), and after ascertaining how reproducible were the results obtained at the start of this survey (Appendix 4). A hit was recorded when at soil level a point struck, (a) the crown of an erect

species, (b) the rooted stem of a mat-grass or other prostrate species, or (c) the rosette leaves of any species. Only low-growing shrubs were encountered and a hit at any level on the branches and foliage of these was recorded. These criteria were considered to ensure that the plant recorded did fully occupy the area concerned and made it unlikely that another plant could establish itself at that spot.

The data obtained are expressed as percentage basal cover, and as percentage composition.

Percentage basal cover for species A =

$$\frac{\text{No. of hits recorded for species A}}{\text{Total no. of points projected}} \times 100.$$

Percentage composition for species A =

$$\frac{\text{No. of hits recorded for species A}}{\text{Total no. of hits for all species}} \times 100.$$

The point transect method gave sufficient information about the grasses, sedges, and the more abundant forbs, but not about the subdominant species. For this reason, 20 count-list metre-quadrats were recorded on each site.

The data obtained from the quadrats is expressed as percentage frequency, and as density.

Percentage frequency for species A =

$$\frac{\text{No. of quadrats in which species A was recorded}}{\text{Total no. of quadrats observed}} \times 100.,$$

and density for species A =

The number of plants of species A counted in 20 metre-quadrats.

Data obtained from such a survey must be carefully inter-

preted in the light of evidence obtained by Clapham (1936), Blackman (1942), and Ashby (1948), that perennial species in a community tend to follow neither a normal nor a Poisson distribution. Clapham states, "In general it can be said that the number of different species occurring in a small area of vegetation is much smaller than would be expected from their mean densities on the assumption of random distribution." The species are said to be 'over dispersed'. In view of this, and because subjective criteria were used in the initial choice of sites, statistical analysis was not applied to the quadrat and the point transect data. The point-transect method, which consists essentially of recording data from numerous 'quadrats' each of infinitesimal area, has been used in pasture research in many countries and is generally considered to be both objective and rapid (Crocker and Tiver 1948). Because of the smallness of the area under consideration at any one time an accurate reading can be made; and because it is possible to make a large number of readings a very accurate and reproducible estimation of the botanical composition of a sward, in terms of the dominant species, can be obtained. The metre-quadrat data while giving further information about all the less abundant species were most useful in providing information on the autecology of certain species and especially on the distribution of plant families and societies in relation to microclimatic effects.

The upper slopes of knolls and the depressional areas were avoided during sampling.

On areas of rolling topography it was recognized that the vegetation on the upper slopes and the associated soils were held in a preclimax condition, although not necessarily at the same successional stage (Tansley 1935), by extreme microclimatic effects. The extreme conditions operating are occasioned by a number of factors. In this region rainfall is sparse and uncertain and evaporation is high (Table 1). The vegetation of the upper slopes, which are continuously exposed to the drying action of the sun and wind, is sparse. Furthermore, winter conditions are severe. The ameliorating effect produced by a blanket of snow is considerable but snow is drifted off the upper slopes thus the vegetation is subjected to extremely low winter temperatures. In these areas of sparse vegetation, runoff and the consequent erosion and leaching of nutrients from the surface soil is excessive. The soils of the lower slopes and the depressions receive the additional runoff water, and the water-borne soil particles and nutrients are deposited. These depressions are occupied by postclimax communities, a more mesophytic type of vegetation than is present on the intermediate or upper slopes. The areas of intermediate slope have more satisfactory drainage, and the vegetation of these slopes is considered to approach most nearly the vegetation of the climatic climax. Sampling was therefore confined to the intermediate slopes, but was at random within this delimitation. In areas of less rolling topography sampling was entirely at random.

The terms preclimax and postclimax are used in the sense

of Weaver and Clements (1938).

As an aid to the interpretation of results obtained by the above sampling methods a study was made of a number of abandoned fields, roadside verges, of relict areas too small to sample, and of a number of disturbed areas. Grasslands in parts of the province outside the scope of the present paper were also sampled.

Sampling of Roots

In order to obtain information of the rooting habits of the dominant species soil cores were taken from a number of sites. The sampling was conducted in September; cores were subsequently washed and the root weights determined. A statistical analysis was applied to the data.

The corer was of very simple design and consisted of a steel cylinder of 2 inches inside diameter (Plate 1). The cylinder was 30 inches long. It had a strengthened cap and holes for a withdrawal bar at one end, and was sharpened at the other. Marking lines were cut on the outside of the cylinder at 2, 6, 12, 18, and 24 inches distance from the sharpened end. The cylinder was driven into the ground with a heavy wooden mallet. When the 2-inch marker line was at ground level the sharpened edge was known to be at a depth of 2 inches. The cylinder was then given a complete turn around at that depth and this severed the root connections between the soil core within the cylinder and the soil beneath. The cylinder was then withdrawn from the hole with the core inside.

The core was removed and placed in a container; the next core, that of the 2 inch to 6 inch soil horizon, was then taken. The depths could be judged accurately by observing the marker lines. The removal of the soil core from the cylinder was effected by tapping the cylinder with a steel rod and in this manner slightly compacting the core which then slid out. In the dry prairie soils it was possible to obtain clean cut cores by this method. In order to obtain an accurate sample it was necessary to retain a keen cutting edge on the cylinder. For this reason, the method is not practicable on stony soils.

An area 20 yards square was marked out on the sites to be sampled. It was endeavoured to locate this square in an area where a number of the dominating species were growing in profusion. Within the conditions described below sampling within the square was at random. The method was found suited to the study of _Bouteloua gracilis_ and _Carex stenophylla enervis_. The former species is a mat former, whereas _C. stenophylla enervis_ characteristically forms a sparse sward with evenly spaced plants. With these species it was possible to sample entirely at random within the area occupied by the mat grass or within the small pure stands of _C. stenophylla enervis_.

A different method had to be adopted when sampling the bunch grasses. One reason for this was that it was not always possible to find the bunch grasses growing in a pure stand, and therefore a precaution had to be taken to ensure that the bulk of the roots within the soil core were the roots of the particular species being sampled. Furthermore, as obviously

a seedling will not produce the same amount of roots as a plant with a large crown, an arbitrary limit of the size of bunch to be sampled had to be made. The following arbitrary limits while being the best that could be devised bring into relief the limitations of this method of sampling when applied to bunch grasses. It was decided that, (a) only bunches not growing within 3 inches of another species would be sampled, and (b) of these plants only those having a crown over 1 inch in diameter would be sampled.

For each of the dominant species eight cores of each separate soil layer were obtained at each site sampled. Thus for species A five samples were obtained, one sample containing eight 0- to 2- inch cores, one sample containing eight 2- to 6- inch cores, and similarly for the 6- to 12- inch, 12- to 18- inch, and 18- to 24- inch soil horizons. To stop respiration all samples were autoclaved on the day of collection. This was done at a pressure of 10- to 15 lbs. per sq. in. for 5 minutes. The samples were then stored until the winter when they were washed and the root weights for each soil layer obtained.

On two sites larger numbers of unbulked single cores were taken and data obtained from these were used in a statistical analysis to obtain a measure of the variability within sites.

The cores were washed over a 60 mesh sieve, (1/120th inch aperture). This sieve allowed the silt and clay particles to pass through but prevented the passage of any visible part of the roots. The roots plus sand, stones, and debris, were trans-

ferred to a tall 1 ml. beaker (Plate 2). After a vigorous stirring three decantations were made, in this way the roots and the debris were poured off into a bowl leaving the sand and stones in the beaker. The debris usually floated above the roots and with the use of tweezers and a camel's hair brush it was possible to remove the debris during the floatation stages. Further floatation in the bowl allowed most of the fine sand and clay particles still remaining to settle out. The roots were then poured off into the 60-mesh sieve and from there transferred to an evaporating dish and dried to constant weight at 100°C. The dry weight was obtained, and subsequently the samples were ashed in a muffle furnace at 700°C. The ash weight was subtracted from the dry weight and the values obtained were used in subsequent calculations. This involves an error incurred in ignoring in the calculations the weight of the elements present within the roots and therefore present in the ash; but this error is considerably less than the error usually countenanced in this kind of work, that of ignoring the weight of soil particles which in spite of a careful washing technique still remain attached to the finer roots.

Greenhouse Studies

Germination tests under controlled moisture and temperature conditions were made on the propagules of a number of species.

The buried viable seed content of a number of sites was determined using methods similar to those used by Brenchley and Warington (1936), and Milton (1943) in England, and by Dore and

Raymond (1942) in Eastern Canada. Sixty-two 0- to 2- inch cores were taken at random on each site using the core sampler. The soil was separated from the herbage and roots and spread in seed boxes to a depth of one inch and overlying steam-sterilized soil. Control boxes containing only the sterilized soil were also made up in order to indicate any contamination by air borne seeds. The seed boxes were brought into a greenhouse. After the first crop of seedlings had been counted and removed the boxes were placed outside for two nights in temperatures below 0°F. On return to the greenhouse the soil in each box was mixed and by this means a second 'crop' was obtained. It was not possible to allow the seedlings to grow to the stage where species would have been identifiable, nor was it possible to obtain more than two 'crops'. Undoubtedly seeds that would have been capable of germination at a later date remained in the boxes.

VEGETATION OF SOIL ASSOCIATIONS

The sites of the present study have been grouped according to the soil Associations as defined by the soil survey of this area (Mitchell _et al_. 1944). The brief description given of the soils within each group applies to the profile characteristics of the sites sampled and not to the soil Association as a whole.

The study area is located within the dark brown soil zone which is a major unit in the classification of the soils of the northern Great Plains. The soil Associations named below comprise local groups of related soil profiles developed on

similar parent materials within the dark brown soil zone.

Weyburn Association

The Weyburn soils are developed on glacial till deposits. The topography is characteristically undulating (Plate 3). Loss of water by runoff is severe on the steeper slopes. A large number of boulders occur throughout the soil profile and many knolls are capped by boulders from between which the finer soil particles have been eroded.

Considerable variation occurs within the Weyburn soils. Gravelly subsoil bands are in evidence on two sites, the presence of small stones and of boulders is more general. Usually some columnar structure is exhibited to a depth of 12 to 18 inches. The depth of the $CaCO_3$ deposition layer varies from 9 inches to 20 inches. Further details are given in Appendix 3.

The sites located on Weyburn soils have been classified in this study into sites on fine-textured soils and sites on coarse-textured soils on the basis of the texture of the top soil and upper subsoil.

(a) Coarse-textured Weyburn soils

Relict sites

Five paired sites were located on coarse-textured Weyburn soils with top soils of light loam and upper subsoils of loam to clay-loam. In addition a relict site was located in the vicinity of one of the paired sites, and two single grazed sites were studied adjacent to paired sites. In all a total of six ungrazed or relict sites and seven grazed sites were

sampled.

Between the capping boulders on the knolls the flora is very restricted and consists in many areas entirely of Selaginella densa and Phlox hoodii (Plates 4 and 5). On eastward-facing slopes and in the depressions, where moisture conditions are more favourable, Symphoricarpos occidentalis and Elaeagnus commutata are often associated with species of Salix and Populus. A number of tall vigorous grasses are associated with the shrubs and trees mentioned; these include Deschampsia caespitosa, Beckmannia syzigachne, and Scolochloa festucacea. The vegetation of similar postclimax communities in the adjacent grassland Associations has been discussed by Coupland (1950) and Coupland and Brayshaw (1953).

The areas are dominated by Stipa spartea curtiseta, Agropyron dasystachyum, and A. smithii, which together make up over 25 percent of the total vegetation (Table 3). Bouteloua gracilis is locally abundant especially where the vegetation is not sufficient to prevent some erosion of the steeper slopes. B. gracilis is able to colonise these bared areas. On these eroding slopes and on the grazed sites this species characteristically produces a dense mat of tillers, which growing outward from the periphery of the mat colonise areas left bare by the death of other plants (Plate 6). In other areas where the vegetation is dense B. gracilis does not form a mat but exhibits a more erect habit of growth. In these situations the tillers, which are of greater length and much more leafy than the prostrate tillers, are supported to some extent by the other vegetation.

TABLE 3

Vegetation on coarse-textured Weyburn soils; data from a point-transect survey of 6 relict and 7 grazed sites.

Species	PERCENTAGE BASAL COVER		PERCENTAGE COMPOSITION	
	Ungrazed	Grazed	Ungrazed	Grazed
Stipa spartea curtiseta	2.08	0.52	13.2	2.0
Agropyron spp.	2.00	0.49	12.6	1.9
Bouteloua gracilis	1.17	2.37	7.4	9.0
Koeleria cristata	0.85	0.75	5.4	2.8
Festuca scabrella	0.33	0.00	2.1	0.0
Stipa comata	0.30	0.12	1.9	0.5
Poa spp.	0.08	0.02	0.5	0.1
Stipa viridula	0.02	0.00	0.1	0.0
Agrostis spp.	0.02	0.00	0.1	0.0
Total grasses	6.85	4.28	43.3	16.2
Carex stenophylla enervis	2.75	5.16	17.4	19.5
Carex pensylvanica digyna	0.20	0.22	1.3	0.8
Carex obtusata	0.00	0.03	0.0	0.1
Total sedges	2.95	5.41	18.7	20.5
Artemisia frigida	3.88	14.03	24.5	53.1
Phlox hoodii	0.23	1.73	1.5	6.6
Other forbs and shrubs	1.90	0.95	12.0	3.6
Total forbs and shrubs	6.02	16.72	38.0	63.3
Total vegetation	15.82	26.41	100.0	100.0

The difference in growth habit of this species when growing in the two habitats is most marked. *Carex stenophylla enervis* has a higher percentage basal cover than any one of the grass species, but because of its small stature and very short growing season it is considered as an interstitial species in this study and therefore is not classified as a dominant. The importance of *Artemisia frigida* varies considerably from site to site. This half-shrub is more abundant on sites located on rolling topography but always comprises over 6.0 percent of the vegetative cover. It is by far the most important of the subdominant species. *Cerastium arvense*, while less frequent than *Selaginella densa* and the short prairie bush roses, occurs locally in great abundance (Table 4). Difficulty was experienced in identifying species of Rosa and the species have been grouped collectively in this paper. *Rosa arkansana* Porter., and *R. alcea* Greene., appear to be the most widespread. In many situations where there is some slight disturbance of the climax vegetation but not enough to destroy the complete cover, *Cerastium arvense* is colonising rapidly. This species was probably not such an important member of the biome as these data tend to suggest.

Grazed sites

On the grazed sites heavy grazing, trampling, and dunging, has killed out the earlier and more productive native grasses such as *Stipa spartea curtiseta*, *Agropyron dasystachyum*, and *A. smithii* (Table 3). Because of a lack of vegetation to hold the protective snow,winter temperatures at ground level tend to be

TABLE 4

Shrubs and forbs on coarse-textured Weyburn soils; data from metre-quadrat counts on 6 relict and 7 grazed sites. Principal species are listed in order of their decreasing frequency on the ungrazed sites.

Species	DENSITY: No. of plants per 20 sq. metres			PERCENTAGE FREQUENCY		
	Ungrazed	Grazed	Response to grazing	Ungrazed	Grazed	Response to grazing
Artemisia frigida	-	-		78	99	Increase
Rosa spp.	52	24		42	30	
Selaginella densa	-	-		27	44	
Anemone patens wolfgangiana	16	32		17	40	
Solidago missouriensis	56	99	Increase	17	26	Increase
Artemisia ludoviciana gnaphalodes	-	-		16	9	
Cerastium arvense	139	10	Decrease	13	4	Decrease
Comandra pallida	10	6		13	6	
Aster ericoides	72	2	Decrease	11	4	
Achillea lanulosa	19	6	Decrease	10	2	Decrease
Androsace puberulenta	5	13		8	12	
Antennaria campestris	-	-		1	0	
Antennaria microphylla	-	-		3	4	
Arabis spp.	0	1		0	4	
Artemisia ludoviciana pabularis	4	0		3	0	
Aster spp.	9	0		5	0	
Astragalus flexuosus	1	0		3	0	
Astragalus spp.	1	1		2	2	
Campanula rotundifolia	0	Tr.		0	1	
Chenopodium spp.	Tr.	0		3	0	
Chrysopsis hirsutissima	0	2		0	8	Increase
Erigeron spp.	Tr.	2		2	3	
Galium boreale	29	12		8	3	Decrease
Geum triflorum	1	29	Increase	3	12	Increase
Grindelia squarrosa quasiperennis	0	Tr.		0	1	
Gutierrezia diversifolia	1	1		2	4	
Heuchera richardsonii	1	1		3	2	

* Tr. = trace

TABLE 4 (Continued)

Species	DENSITY: No. of plants per 20 sq. metres			PERCENTAGE FREQUENCY		
	Ungrazed	Grazed	Response to grazing	Ungrazed	Grazed	Response to grazing
Lepidium densiflorum	0	2		0	1	
Liatris punctata	0	Tr.		0	1	
Orthocarpus luteus	Tr.	Tr.		1	1	
Penstemon spp.	0	Tr.		0	1	
Phlox hoodii	-	-		2	29	Increase
Potentilla camporum	1	4		4	5	
Potentilla strigosa	Tr.	7	Increase	1	14	Increase
Potentilla spp.	1	11	Increase	2	20	Increase
Salsola kali tenuifolia	Tr.	Tr.		1	1	
Solidago rigida	1	0		1	0	
Solidago spp.	0	Tr.		0	1	
Sphaeralcea coccinea	Tr.	1		1	2	
Symphoricarpos occidentalis	2	1		5	1	
Thermopsis rhombifolia	Tr.	2		3	8	Increase

low on these sites. Even on the gentle slopes snow is drifted off with a resultant loss of moisture from the spring thaw. Bouteloua gracilis which commences growth about early May, a month later than the climax dominant grasses, is dominant on these grazed sites. This species is grazed very closely on cattle grazings and even more closely where horses are pastured; however the killing out of other taller more vigorous species has removed most competitors for light and moisture. In addition, Bouteloua gracilis, because of its prostrate growth habit in these situations produces some leaf area that cattle are unable to remove, and where grazing is not too severe the species is colonising bared areas. Carex stenophylla enervis often grows in almost pure stands (Plate 7) and has approximately doubled its percentage basal cover as compared with its cover on the relict sites. Artemisia frigida is more abundant than on the relict sites constituting over 50 percent of the total vegetation. This greater abundance of A. frigida together with the increase of Carex stenophylla enervis accounts for the increase in total vegetative cover on the grazed sites. The decrease in abundance of the grasses, especially of the more productive grasses, is in marked contrast to this.

Of the forbs, Selaginella densa and Phlox hoodii are more abundant on the grazed sites (Table 4). These species have colonised bared and eroded land especially on the steeper slopes. Neither species appears to be grazed. Solidago missouriensis is able to make gains when competing vegetation is removed by grazing, as also are some species of Potentilla. The latter

species are producing many seedlings some of which have had to be grouped under the heading Potentilla spp. as it was impossible to be certain of their identity. *Cerastium arvense* is considerably reduced on the grazed sites. It has been mentioned that this forb increases in locally disturbed areas but only when the vegetative cover is not destroyed as it was by grazing. *C. arvense* is most abundant in grasslands surrounding arable fields.

While the percentage basal cover of the total vegetation is greater on the grazed sites, the percentage contributed by the valuable forage species is less. Because of the increase of *Carex stenophylla enervis* the total basal cover for the total of grasses plus sedges remains almost constant; however *Carex stenophylla enervis* cannot be considered to be a valuable forage plant because of its lack of vigour, its small stature, and its short growing season. Although the value of pasture forbs in the nutrition of the grazing animal has been clearly shown (Thomas *et al.* 1952), the forb population on these pastures is too high compared with that of the more valuable grasses. The change in the population is due principally to an increase of *Artemisia frigida* and *Phlox hoodii*. *A. frigida* was observed to be grazed when in the seeding stage but only on pastures that were very bare. *Phlox hoodii* is not grazed at all.

Table 4 shows that the Leguminosae is sparsely represented by species of Astragalus and by *Thermopsis rhombifolia*.

(b) Fine-textured Weyburn soils

Relict sites

Two paired sites and two additional grazed sites were sampled on heavier Weyburn soils. The top soil textures are loams and upper sub-soil textures clay-loams. On these soils the topography is of a more rolling phase. In consequence of the steeper slopes and finer-textured surface soils of these sites runoff is more complete. Again the glacial boulders are very much in evidence and the depressions support a postclimax vegetation dominated by Symphoricarpos occidentalis and species of Salix and Populus. On these finer-textured soils Agropyron dasystachyum and A. smithii are of less importance (Table 5). The dominants Stipa spartea curtiseta and Koelaria cristata are here joined by Festuca scabrella a coarser more vigorous grass that dominates the grasslands to the north of the study area (Coupland and Brayshaw 1953). Carex stenophylla enervis is again the principal sedge. Although on the steeper slopes there is more runoff, in the many small depressions and on the more gentle slopes the greater water retention of these soils allows the growth of a more luxuriant vegetation. Festuca scabrella is confined to these positions. Artemisia frigida is very abundant and occurs in almost every quadrat (Table 6). The forb population on these sites is exceptionally high, Selaginella densa, Solidago missouriensis and Anemone patens wolfgangiana being the most abundant.

In the Fescue grasslands to the north, Brayshaw (1951), using similar techniques, reported the frequency and the density of A. patens wolfgangiana to be 82 percent and 162 respectively

TABLE 5

Vegetation on fine-textured Weyburn soils; data from a point-transect survey of 2 relict and 4 grazed sites.

Species	PERCENTAGE BASAL COVER		PERCENTAGE COMPOSITION	
	Ungrazed	Grazed	Ungrazed	Grazed
Stipa spartea curtiseta	4.10	0.81	19.6	2.8
Koeleria cristata	1.15	0.87	5.5	3.0
Festuca scabrella	0.85	0.03	4.1	0.1
Bouteloua gracilis	0.55	1.84	2.6	6.4
Agropyron spp.	0.35	0.41	1.7	1.4
Poa spp.	0.00	0.03	0.0	0.1
Total grasses	7.00	3.97	33.4	13.8
Carex stenophylla enervis	1.80	5.25	8.6	18.3
Carex praegracilis	0.05	0.00	0.2	0.0
Carex pensylvanica digyna	0.00	0.21	0.0	0.7
Total sedges	1.85	5.45	8.8	19.0
Artemisia frigida	10.15	14.76	48.5	51.3
Phlox hoodii	0.10	2.66	0.5	9.2
Other forbs and shrubs	1.85	1.93	8.8	6.7
Total forbs and shrubs	12.10	19.34	57.8	67.2
Total vegetation	20.95	28.76	100.0	100.0

TABLE 6

Shrubs and forbs on fine-textured Weyburn soils; data from metre-quadrat counts on 2 relict and 4 grazed sites. Principal species are listed in order of their decreasing frequency on the ungrazed sites.

Species	DENSITY: No. of plants per 20 sq. metres			PERCENTAGE FREQUENCY		
	Ungrazed	Grazed	Response to grazing	Ungrazed	Grazed	Response to grazing
Artemisia frigida	-	-		98	100	
Anemone patens wolfgangiana	153	112		85	70	
Selaginella densa	-	-		48	43	
Solidago missouriensis	105	90		45	30	
Astragalus flexuosus	28	Tr.	Decrease	35	3	Decrease
Comandra pallida	31	9	Decrease	28	13	Decrease
Geum triflorum	22	111	Increase	23	29	Increase
Rosa spp.	30	15		23	20	
Androsace puberulenta	9	2	Decrease	23	9	Decrease
Achillea lanulosa	32	7		20	3	
Aster ericoides	45	12	Decrease	20	11	
Potentilla strigosa	6	85	Increase	20	54	Increase
Phlox hoodii	-	-		13	29	Increase
Antennaria microphylla	-	-		3	10	
Arabis holboellii retrofracta	Tr.	0		3	0	
Artemisia ludoviciana gnaphalodes	-	-		8	6	
Aster spp.	1	6		3	1	
Astragalus spp.	0	1		0	3	
Campanula rotundifolia	0	7		0	3	
Capsella bursa-pastoris	0	Tr.		0	1	
Cerastium arvense	5	0		3	0	
Chenopodium spp.	0	Tr.		0	3	
Chrysopsis hirsutissima	0	1		0	3	
Elaeagnus commutata	1	0		3	0	
Erigeron caespitosus	0	13		0	3	
Erigeron spp.	9	Tr.		5	1	
Galium boreale	0	Tr.		0	1	

TABLE 6 (Continued)

Species	DENSITY: No. of plants per 20 sq. metres			PERCENTAGE FREQUENCY		
	Ungrazed	Grazed	Response to grazing	Ungrazed	Grazed	Response to grazing
Gentiana strictiflora	0	Tr.		0	1	
Gutierrezia diversifolia	1	17	Increase	5	20	Increase
Haplopappus spinulosus	7	2		5	6	
Heuchera richardsonii	0	Tr.		0	1	
Liatris punctata	0	Tr.		0	1	
Linum lewisii	Tr.	1		3	3	
Lygodesmia juncea	4	2		5	4	
Orthocarpus luteus	Tr.	2		3	1	
Potentilla camporum	1	3		5	0	
Potentilla spp.	0	Tr.		0	1	
Solidago spp.	0	1		0	1	
Sphaeralcea coccinea	1	0		3	0	
Symphoricarpos occidentalis	2	1		8	3	
Thermopsis rhombifolia	Tr.	2		5	4	

in the Stipa-Festuca faciation. In the Festuca scabrella consociation he reported the density to be 155 and the percentage frequency to be 68. This corresponds with the findings of this survey (Table 6). Coupland (1950) working on mixed prairie to the south, reported that even where most abundant the species seldom occurred with an abundance of more than 20 and a percentage frequency of more than 25. It may be that similar habitat conditions favor both Festuca scabrella and A. patens wolfgangiana.

Astragalus flexuosus is of greater abundance on these finer-textured soils than is the case on the lighter soils.

Grazed sites

On the grazed sites Bouteloua gracilis is dominant as it was on the lighter soils (Table 5). Koeleria cristata is reduced in basal cover but not to the extent of Stipa spartea curtiseta. It should be noted that this is paralleled on the lighter soils, K. cristata suffers less from the effects of grazing than does S. spartea curtiseta. As both are erect bunch grasses this difference in response to grazing is not attributable to a different habit of growth as is the case with Bouteloua gracilis. It would appear from observations that Koeleria cristata is somewhat less palatable, at least at certain seasons, than S. spartea curtiseta and is not such a vigorous grass. Moss (1952) working on the Peace River grasslands of northwestern Alberta reported an increase of K. cristata under grazing conditions and an associated decrease in the abundance of S. spartea curtiseta.

Festuca scabrella suffers severely from grazing. This

species is a vigorous bunch grass and is probably the most productive of the grasses present. F. scabrella is not preferentially grazed but because of the lack of other forage in the mid-summer period it is tightly grazed down. In spite of a reduction of the grass cover the total basal cover of grasses and sedges remains almost constant. This is due to an increase of Carex stenophylla enervis.

Astragalus flexuosus is rarely found on the grazed sites (Table 6). Another legume, Thermopsis rhombifolia, is not reduced. Two rosette species Potentilla strigosa and Geum triflorum are more abundant on the grazed sites on both the fine- and the coarse-textured soils. Phlox hoodii has again colonised areas on the slopes which have been bared by grazing and trampling followed by erosion. Gutierrezia diversifolia is of greater abundance than on the coarse-textured soils, whereas the reverse is true of Cerastium arvense and Artemisia ludoviciana gnaphalodes.

On both the coarse- and the fine-textured soils a considerable percentage of the vegetation of protected and grazed sites is made up by Artemisia frigida. On both soil types, in spite of a marked reduction of grasses under grazing, the total basal cover of the vegetation has increased because of an increase in A. frigida and Carex stenophylla enervis. Even under extreme grazing conditions these two species are spreading vegetatively and by seed.

Elstow Association

Four paired sites and one additional grazed site were

studied on Elstow soils. The soils of this Association are developed on silty lacustrine deposits. The topography while being undulating is of a less rolling phase than that of the Weyburn soils. There is a considerable range in texture of the soils of this Association. The range of top soil textures is from light loam to clay-loam. The subsoils are more fine than the Weyburn soils and the soils as a whole more drought resistant. The heavy underlying silty-clay horizon was examined at most sites. This horizon, which exhibited marked varving, is at greatly varying depths on different sites (Appendix 3). On one site there is some evidence that wind working subsequent to deposition may have contributed to this variation. Glacial boulders are not in evidence on any of the sites studied; this suggests that the lacustrine deposition was of some depth. The high percentage of silt in these surface soils makes them subject to drifting. Erosion is in evidence on all the heavily grazed sites examined on the more rolling phases.

Relict sites

Agropyron dasystachyum, A. smithii, and Stipa spartea curtiseta are dominant on the protected sites as they are on the coarse textured Weyburn soils (Table 7). Bouteloua gracilis is well established on all the sites. This species, which does not achieve dominance in the climax grassland of the area, is always present as a sub-dominant. In almost every case B. gracilis makes considerable gains when competing species are checked by grazing. Carex stenophylla enervis and Artemisia frigida together contribute over 40 percent of the vegetation.

TABLE 7

Vegetation on Elstow soils; data from a point-transect survey of 4 relict and 5 grazed sites.

Species	PERCENTAGE BASAL COVER		PERCENTAGE COMPOSITION	
	Ungrazed	Grazed	Ungrazed	Grazed
Agropyron spp.	2.08	1.38	14.2	6.0
Stipa spartea curtiseta	1.73	0.34	11.8	1.5
Bouteloua gracilis	0.80	3.04	5.5	13.2
Koeleria cristata	0.70	0.62	4.8	2.7
Festuca scabrella	0.28	0.00	1.9	0.0
Stipa viridula	0.25	0.00	1.7	0.0
Stipa comata	0.05	0.02	0.3	0.1
Poa spp.	0.03	0.00	0.2	0.0
Muhlenbergia richardsonis	0.00	0.04	0.0	0.2
Total grasses	5.90	5.44	40.3	23.7
Carex stenophylla enervis	2.80	4.32	19.1	18.8
Carex pensylvanica digyna	0.63	0.06	4.3	0.3
Carex lasiocarpa americana	0.03	0.00	0.2	0.0
Total sedges	3.45	4.38	23.6	19.0
Artemisia frigida	3.45	12.08	23.6	52.5
Phlox hoodii	0.03	0.34	0.2	1.5
Other forbs and shrubs	1.80	0.76	12.3	3.3
Total forbs and shrubs	5.28	13.18	36.1	57.3
Total vegetation	14.63	23.00	100.0	100.0

It is possible that slight disturbance of some of the relict sites has favored the two species. The author thinks that even if this is the case these species must have been of considerable importance in the biome.

Grazed sites

On the grazed sites Bouteloua gracilis is dominant (Table 7). Agropyron dasystachyum and A. smithii are not as greatly reduced as Stipa spartea curtiseta which has been closely grazed. On one site the species of Agropyron retain dominance. Two more vigorous grasses, Stipa viridula and Festuca scabrella, are present scattered over two relict sites, while in the adjacent grazed sites these species are not to be found. Carex stenophylla enervis is more abundant on the grazed sites, but Carex pensylvanica digyna a taller and more mesophytic species is reduced in abundance. Artemisia frigida has increased under grazing as has Selaginella densa and Phlox hoodii (Table 8). The two forbs are most in evidence on the steeper eroding slopes. Grindelia squarrosa quasiperennis did not occur during the whole survey in totally undisturbed grassland. This species is always associated with a break in the vegetative cover, especially when this is adjacent to an arable field. This is also true of Lepidium densiflorum. Of the forbs that are less abundant on the grazed sites Cerastium arvense, Achillea lanulosa, and Aster ericoides, are reduced under grazing on all three soil groups so far considered.

Biggar Association

Three paired sites were studied on the Biggar gravelly

TABLE 8

Shrubs and forbs on Elstow soils; data from metre-quadrat counts on 4 relict and 5 grazed sites. Principal species are listed in order of their decreasing frequency on the ungrazed sites.

Species	DENSITY: No. of plants per 20 sq. metres			PERCENTAGE FREQUENCY		
	Ungrazed	Grazed	Response to grazing	Ungrazed	Grazed	Response to grazing
Artemisia frigida	-	-		76	96	Increase
Aster ericoides	67	5	Decrease	24	10	Decrease
Selaginella densa	-	-		20	41	Increase
Cerastium arvense	254	7	Decrease	20	3	Decrease
Achillea lanulosa	49	3	Decrease	19	4	Decrease
Anemone patens wolfgangiana	22	8		21	22	
Rosa spp.	25	8		16	13	
Solidago missouriensis	28	32		14	10	
Potentilla strigosa	34	6		14	10	
Geum triflorum	10	4		10	7	
Allium textile	0	Tr.		0	1	
Androsace puberulenta	Tr.	7		1	6	
Antennaria campestris	-	-		3	2	
Antennaria microphylla	-	-		3	7	
Arabis spp.	0	1		0	3	
Artemisia biennis	Tr.	0		1	0	
Artemisia ludoviciana gnaphalodes	103	1	Decrease	8	1	Decrease
Aster coerulescens	0	1		0	1	
Aster spp.	23	Tr.		3	1	
Astragalus spp.	Tr.	1		1	3	
Chenopodium spp.	2	Tr.		5	1	
Comandra pallida	3	1		3	3	
Galium boreale	8	3		1	2	
Geum aleppicum strictum	0	Tr.		0	1	
Grindelia squarrosa quasiperennis	0	12	Increase	0	8	Increase
Gutierrezia diversifolia	Tr.	2		3	8	
Heuchera richardsonii	Tr.	Tr.		1	1	

TABLE 8 (Continued)

Species	DENSITY: No. of plants per 20 sq. metres			PERCENTAGE FREQUENCY		
	Ungrazed	Grazed	Response to grazing	Ungrazed	Grazed	Response to grazing
Lepidium densiflorum	2	20		5	9	
Orthocarpus luteus	0	Tr.		0	1	
Phlox hoodii	-	-		-	15	Increase
Polygonum aviculare	0	1		0	2	
Potentilla camporum	0	3		0	5	
Potentilla spp.	20	3		6	8	
Scirpus spp.	0	Tr.		0	1	
Symphoricarpos occidentalis	0	Tr.		0	2	
Taraxacum spp.	0	1		0	2	
Thermopsis rhombifolia	4	1		3	3	

loams. These soils extend over a large area of fairly level land. The underlying gravels were probably outwash from the retreating ice when the glacial lake was shallow. The topsoil textures of the sites studied are sandy-loams and loams. The outwash gravels are overlain by about 9 inches of soil (Appendix 3). Profile drainage on these soils is excessive,and although runoff is negligible only the deep rooting perennial species are able to reach the subsoil moisture. On these soils annual crops suffer severely from drought. Practices such as haying or grazing tend to reduce the rooting depth and vigour of perennial plants and the results are often serious. Because of the drought conditions a number of farms in the area have been abandoned.

The postclimax situations on this soil type support a more mesic vegetation than the other soils of the present study area, probably because of favourable lower subsoil moisture conditions. The postclimax vegetation of the depressions may be considered as outliers of the aspen grove community which is to the north of these grasslands. Coupland and Brayshaw (1953) have discussed the ecology of this northern community.

Relict sites

Festuca scabrella and *Stipa spartea curtiseta* dominate the relict sites. Although *F. scabrella* characteristically produces a dense foliage this is not suggested by the low percentage basal cover recorded (Table 9). During this survey it was constantly found that where herbage is dense there is much bare ground between the crowns of the grasses. Species are

TABLE 9

Vegetation on Biggar soils; data from a point-transect survey of 3 relict and 3 grazed sites.

Species	PERCENTAGE BASAL COVER		PERCENTAGE COMPOSITION	
	Ungrazed	Grazed	Ungrazed	Grazed
Festuca scabrella	2.32	0.35	13.4	1.5
Stipa spartea curtiseta	1.75	0.46	10.1	2.0
Koeleria cristata	0.91	2.60	5.2	11.3
Helictotrichon hookeri	0.31	0.03	1.8	0.1
Agropyron spp.	0.28	0.39	1.6	1.7
Bouteloua gracilis	0.23	0.96	1.3	4.2
Poa spp.	0.13	0.07	0.8	0.3
Festuca ovina	0.05	0.00	0.3	0.0
Total grasses	5.98	4.88	34.5	21.2
Carex stenophylla enervis	1.25	2.11	7.2	9.2
Carex obtusata	0.61	0.30	3.5	1.3
Carex pensylvanica digyna	0.00	0.77	0.0	3.4
Total sedges	1.85	3.18	10.7	13.9
Artemisia frigida	1.85	3.91	10.7	17.0
Phlox hoodii	1.10	1.07	6.3	4.7
Other forbs and shrubs	6.55	9.94	37.8	43.3
Total forbs and shrubs	9.50	14.92	54.8	64.9
Total vegetation	17.33	22.98	100.0	100.0

not able to establish by seed in these areas because of the dense canopy of foliage.

Coupland and Brayshaw (1953) have investigated the rooting depth of Festuca scabrella, Stipa curtiseta and Koeleria cristata on this soil type and within five miles of all the present sites. They found roots of F. scabrella always at 4.0 feet and estimated the average rooting depth of this species to be 5.0 feet. Stipa spartea curtiseta and Koeleria cristata were found to be more shallow rooting; the roots of these species did not extend below 3.5 to 4.0 feet. These studies were conducted on relict grasslands.

Festuca scabrella is dominant under conditions of higher rainfall and lower evaporation to the north. This deeply-rooting species appears able to obtain the subsurface moisture from the well drained coarse-textured Biggar soils, and the Fescue grasslands extend to their most southerly position in this area on a narrow tongue of these soils. Stipa comata and Bouteloua gracilis are less abundant in the Fescue grasslands than they are in the mixed prairie to the south. Table 9 shows that in the grasslands on Biggar soils the former species is entirely absent, and the latter is of decreased abundance relative to its abundance on other soil Associations and in association with other species. Carex stenophylla enervis is also of reduced abundance, but C. obtusata was found to be abundant in localized areas where moisture conditions are more favorable. On other soils this sedge is associated with Festuca scabrella in situations that are receiving additional runoff moisture.

Artemisia frigida is less abundant than heretofore but the forbs are important and make up the bulk of the vegetation. *Aster ericoides* is particularly widespread over the whole area (Table 10).

Grazed sites

Koeleria cristata is dominant on all the grazed sites (Table 9). *Festuca scabrella* and *Stipa spartea curtiseta* are very much reduced in importance. This is possibly associated with a reduction in rooting depth of these species following defoliation. *Bouteloua gracilis*, while of greater extent than in the relict grasslands and the second most abundant grass, has not made the considerable gains under grazing that are common on other soils. Neither are the sedges so important on these droughty soils. The pastures are not gray with the foliage of *Artemisia frigida* as are pastures on other soils, nevertheless this species has increased in extent. On these less rolling grasslands *Selaginella densa* and *Phlox hoodii* have made only slight gains (Table 10). *Geum triflorum* and *Potentilla strigosa* have again made considerable gains and of interest is the increase of the rhizomatous *Comandra pallida* (Plate 8). The ability to reproduce vegetatively is at a premium under grazing conditions. Five species of the Leguminosae are present but not in any abundance; however, they appear to have suffered no decrease following grazing. In all groups considered so far, in spite of marked fluctuations in the relative abundance of the species, the total basal cover of the grasses and sedges has been almost the same on both grazed and relict sites.

TABLE 10

Shrubs and forbs on Biggar soils; data from metre-quadrat counts on 3 relict and 3 grazed sites. Principal species are listed in order of their decreasing frequency on the ungrazed sites.

Species	DENSITY: No. of plants per 20 sq. metres			PERCENTAGE FREQUENCY		
	Ungrazed	Grazed	Response to grazing	Ungrazed	Grazed	Response to grazing
Solidago missouriensis	1119	644	Decrease	75	65	Decrease
Anemone patens wolfgangiana	80	120		60	83	
Selaginella densa	-	-		58	65	
Achillea lanulosa	92	289		57	53	
Rosa spp.	47	46		57	45	Decrease
Artemisia frigida	-	-		55	68	
Cerastium arvense	183	233		50	55	
Artemisia ludoviciana gnaphalodes	-	-		45	32	Decrease
Aster ericoides	222	204		40	38	
Comandra pallida	28	42	Increase	30	52	Increase
Galium boreale	113	138	Increase	28	42	Increase
Solidago rigida	25	13	Decrease	22	5	Decrease
Phlox hoodii	-	-		20	32	
Heuchera richardsonii	7	4		18	10	
Artemisia biennis	9	27	Increase	17	45	Increase
Androsace puberulenta	5	10	Increase	12	23	Increase
Antennaria campestris	-	-		6	2	
Antennaria microphylla	-	-		5	32	Increase
Arabis spp.	0	Tr.		0	2	
Artemisia ludoviciana pabularis	-	-		2	0	
Aster spp.	0	20		0	3	
Astragalus spp.	3	5		7	7	
Campanula rotundifolia	7	30	Increase	13	20	Increase
Chrysopsis hirsutissima	4	2		12	5	
Erigeron caespitosus	10	0		10	0	
Erigeron glabbelus	Tr.	8		2	5	

TABLE 10 (Continued)

Species	DENSITY: No. of plants per 20 sq. metres			PERCENTAGE FREQUENCY		
	Ungrazed	Grazed	Response to grazing	Ungrazed	Grazed	Response to grazing
Erigeron spp.	0	2		0	5	
Gaillardia aristata	7	1		3	5	
Gentiana strictiflora	1	6		3	3	
Geum triflorum	3	61	Increase	10	32	Increase
Liatris punctata	0	1		0	3	
Orthocarpus luteus	8	64		12	12	
Oxytropis spp.	0	2		0	5	
Potentilla camporum	3	1		7	3	
Potentilla strigosa	3	23	Increase	7	40	Increase
Potentilla spp.	2	0		7	0	
Psoralea argophylla	0	Tr.		0	2	
Solidago decumbens oreophila	3	1		8	3	
Solidago dumetorum	Tr.	1		2	3	
Sphaeralcea coccinea	0	1		0	3	
Thermopsis rhombifolia	1	2		2	7	
Vicia sparsifolia	1	Tr.		3	2	
Viola adunca	23	7		5	3	

An area adjacent to one of the sites has been abandoned for the last six years following overgrazing. It was plain from the comparison of the two areas that grasslands on this soil type and under these semi-arid conditions recover very slowly from such treatment. The site of an old fence line that once separated the two fields can be picked out with ease. The abandoned area has been colonised by many forbs, and the more valuable grass species are spreading slowly against such competition.

Asquith Association

These soils are developed on sandy lacustrine and alluvial deposits. One paired site, and in addition two relict and three grazed sites were sampled. The topsoil textures are fine sandy-loams and light loams, and the upper and middle subsoil textures sandy-loams to sandy-clay-loams (Appendix 3). All the soils exhibit columnar structure to a depth of 15 inches. The profile drainage is excessive and the soils droughty, with the exception that on the paired site conditions are ameliorated by a silty clay horizon at about 22 inches; however it was considered that the conditions are similar enough for the sites to be comparable (Plate 9). The topography is gently undulating. Runoff is slight. Wind erosion is in evidence on the more severely grazed areas.

Relict sites

The relict grasslands are dominated by *Stipa spartea curtiseta* and *Bouteloua gracilis* (Table 11). *Stipa comata* is

TABLE 11

Vegetation on Asquith soils; data from a point-transect survey of 3 relict and 4 grazed sites.

Species	PERCENTAGE BASAL COVER		PERCENTAGE COMPOSITION	
	Ungrazed	Grazed	Ungrazed	Grazed
Stipa spartea curtiseta	2.88	2.50	18.3	15.9
Bouteloua gracilis	1.05	3.30	6.7	21.0
Stipa comata	0.81	0.18	5.1	1.2
Koeleria cristata	0.63	0.40	4.0	2.6
Agropyron spp.	0.43	0.23	2.7	1.5
Festuca scabrella	0.30	0.00	1.9	0.0
Total grasses	6.10	6.60	38.7	42.0
Carex stenophylla enervis	5.46	3.75	34.6	23.9
Carex pensylvanica digyna	0.31	0.03	2.0	0.2
Total sedges	5.77	3.78	36.6	24.1
Artemisia frigida	2.78	4.10	17.6	26.1
Phlox hoodii	0.14	0.23	0.9	1.5
Other forbs and shrubs	0.98	1.00	6.2	6.4
Total forbs and shrubs	3.90	5.32	24.7	33.9
Total vegetation	15.77	15.70	100.0	100.0

of greater abundance on these drier soils. This species has replaced Stipa spartea curtiseta and other species in preclimax and other xerophitic situations throughout the area of study. Festuca scabrella is only present on these soils in postclimax situations. This species often occurs in a zone surrounding the shrub communities occupying depressions. Carex stenophylla enervis is abundant. Herbage is not dense and competition not so strong for this low-growing species as is the case on other soils. Mainly because of the increased importance of this species the total abundance of grasses plus sedges is greater than on the other soil types.

Artemisia frigida and the low-growing prairie roses are abundant (Table 12). It may be recalled that these species of Rosa occurred in almost 60 percent of the quadrats on the thin soils overlying outwash gravels. Coupland (1950) refers to the increased vigour of Rosa arkansana on sandy patches in areas of heavier soil. Selaginella densa and Phlox hoodii are important in local areas, usually in preclimax conditions on the tops of the small knolls. In these positions they are often in association with Carex stenophylla. Sphaeralcea coccinea is more frequent on this soil Association than on the others. Coupland (1950) has found this attractive red-flowered forb to be frequent in mixed prairie, reporting this frequency to be between 26 and 30 percent. S. coccinea occurs in large socies where mixed prairie has been disturbed. In the present study area the species is much less frequent, occurring at its maximum frequency of 7 percent on these Asquith soils. Table 12 shows a greater abund-

TABLE 12

Shrubs and forbs on Asquith soils; data from metre-quadrat counts on 3 relict and 4 grazed sites. Principal species are listed in order of their decreasing frequency on the ungrazed sites.

Species	DENSITY: No. of plants per 20 sq. metres			PERCENTAGE FREQUENCY		
	Ungrazed	Grazed	Response to grazing	Ungrazed	Grazed	Response to grazing
Artemisia frigida	-	-		72	96	Increase
Rosa spp.	84	19	Decrease	58	21	Decrease
Selaginella densa	-	-		42	18	Decrease
Anemone patens wolfgangiana	11	1	Decrease	23	4	Decrease
Solidago missouriensis	44	0	Decrease	15	0	Decrease
Potentilla strigosa	7	19	Increase	13	36	Increase
Phlox hoodii	-	-		13	9	
Chrysopsis hirsutissima	4	1		12	3	
Androsace puberulenta	Tr.	6	Increase	2	11	Increase
Arabis spp.	1	2		3	3	
Artemisia ludoviciana gnaphalodes	-	-		5	1	
Aster ericoides	3	3		3	4	
Aster spp.	0	Tr.		0	1	
Astragalus flexuosus	0	1		0	3	
Capsella bursa-pastoris	0	Tr.		0	1	
Cerastium arvense	Tr.	14		2	1	
Chenopodium spp.	0	3		0	9	Increase
Elaeagnus commutata	0	0		0	1	
Equisetum spp.	4	0		5	0	
Erigeron spp.	0	Tr.		0	1	
Gaura coccinea	Tr.	0		2	0	
Gutierrezia diversifolia	0	Tr.		0	3	
Lepidium densiflorum	0	10	Increase	0	13	Increase
Liatris punctata	0	Tr.		0	1	
Lygodesmia juncea	2	2		3	10	
Oenothera spp.	0	1		0	1	
Polygonum aviculare	0	2		0	6	

TABLE 12 (Continued)

Species	DENSITY: No. of plants per 20 sq. metres			PERCENTAGE FREQUENCY		
	Ungrazed	Grazed	Response to grazing	Ungrazed	Grazed	Response to grazing
Potentilla spp.	Tr.	204	Increase	2	55	Increase
Salsola kali tenuifolia	0	6	Increase	0	11	Increase
Sphaeralcea coccinea	15	33	Increase	7	23	Increase
Symphoricarpos occidentalis	1	0		5	0	
Thermopsis rhombifolia	0	4	Increase	0	11	Increase

ance of the species on the disclimax sites.

Grazed sites

Stipa spartea curtiseta, *Bouteloua gracilis* and *Koeleria cristata* are the dominant species on the grazed sites (Table 11). Because of the sandy nature of the top soil, the semi-arid climatic conditions, and excessive trampling by stock, there is a total absence of soil structure to a depth of about 1 inch. The structureless soil is subject to drifting. In consequence, on the most heavily grazed sites there is a reduction of rooting in the surface soil horizon. The conditions for growth are so severe that few of the grass species are able to survive. The ability of the erect bunch grasses, *S. spartea curtiseta* and *K. cristata*, to keep in the sward under such conditions is rather surprising. *S. spartea curtiseta* is important in all the grazed sites and is the major dominant on two of these. *Bouteloua gracilis* is of more importance on the grazed sites than on the ungrazed, but where the grazing and treading is heavy, especially where horses are pastured, it is not colonising the many bared areas. *Carex stenophylla* while of reduced extent on the grazed areas is still important in the total vegetative cover. *Artemisia frigida* is one of the few species able to set seed under the severe conditions. Species of Rosa are less frequent on the grazed sites; this is also true of the situation on the other soil Associations.

Adjacent to one of the grazed sites was a pasture through which a strip had been ploughed 40 years previous to this study. This strip is reported to have been abandoned 35 years ago and

the area is now in a successional stage approaching that of the grazing disclimax of the surrounding pasture. The limits of this strip are still in evidence because of the greater abundance of Selaginella densa in this open seral community. This species is favoured by conditions that tend to open the cover of the climax grassland, if these conditions are not associated with heavy trampling.

The importance of Potentilla strigosa is not fully brought out by the data (Table 12). Considerable germination of Potentilla seedlings made individual identification impossible. These seedlings are grouped as Potentilla spp. but undoubtedly include many seedlings of P. strigosa. In pastures adjacent to arable fields there has been some colonising of bared patches by ruderals, notably Salsola kali tenuifolia, and Lepidium densiflorum. In spite of the fact that the basal cover of the total grasses is as high on the grazed as on the ungrazed sites, because the slight increase of the forb population does no more than balance the unusual decrease in total sedges the basal cover of the total vegetation is approximately equal under the two managements. This is in marked contrast to results obtained on the other soil types.

Dune Sands

The soils of this group are weakly developed on a parent material of wind worked alluvial sands. There has been very little accumulation of humus and little profile development. The top soil textures are loamy-sands and sands (Appendix 3).

Below this sand occurs to a considerable depth. Two paired grassland sites and an additional relict site were studied. The topography is of the typical dune type (Plate 10). There is little runoff and profile drainage is excessive. The water table is deep.

Relict sites

The relict areas are dominated by Stipa comata and Bouteloua gracilis (Table 13). Calamovilfa longifolia is less abundant but is widespread over the area. This species is reported to be indicative of a high degree of stabilization in sandy areas (Mueller 1941). Stipa comata is less vigorous than S. spartea curtiseta in the present study area and subservient to this species on the better soils. These sites approach the most northerly distribution of S. comata in this area. Sarvis (1923) working in North Dakota found S. comata to be short-lived and very dependent upon reseeding. The seeds of both species of Stipa are often effectively planted to some depth by the twisting action of the hygroscopic awn which is a feature of the propagules (Plate 11). Even on heavy soils the seeds have been observed during this survey at a depth of 1 inch, still with the awn attached, and still presumably capable of deeper implantation.

The sedges are not abundant on these dune sand grasslands although Carex stenophylla is widespread and Carex pensylvanica digyna occurs in many of the small depressions. Artemisia frigida is more vigorous than on any other soil type. Chrysopsis hirsutissima is the most abundant forb (Table 14).

TABLE 13

Vegetation on Dune sands (Stipa-Bouteloua Faciation); data from a point-transect survey of 3 relict and 2 grazed sites

Species	PERCENTAGE BASAL COVER		PERCENTAGE COMPOSITION	
	Ungrazed	Grazed	Ungrazed	Grazed
Stipa comata	3.39	1.62	19.6	7.8
Bouteloua gracilis	2.07	1.78	12.0	8.6
Calamovilfa longifolia	0.63	0.04	3.7	0.2
Koeleria cristata	0.32	0.32	1.9	1.5
Stipa spartea curtiseta	0.05	0.08	0.3	0.4
Agropyron spp.	0.02	0.00	0.1	0.0
Total grasses	6.51	3.83	37.7	18.4
Carex stenophylla enervis	1.27	0.86	7.4	4.1
Carex pensylvanica digyna	0.43	0.09	2.5	0.4
Total sedges	1.70	0.95	9.8	4.6
Artemisia frigida	6.44	14.14	37.3	68.0
Phlox hoodii	1.00	0.67	5.8	3.2
Other forbs and shrubs	1.62	1.22	9.4	5.9
Total forbs and shrubs	9.06	16.02	52.5	77.0
Total vegetation	17.27	20.80	100.0	100.0

TABLE 14

Shrubs and forbs on Dune sands (Stipa-Bouteloua Faciation); data from metre-quadrat counts on 3 relict and 2 grazed sites. Principal species are listed in order of their decreasing frequency on the ungrazed sites.

Species	DENSITY: No. of plants per 20 sq. metres			PERCENTAGE FREQUENCY		
	Ungrazed	Grazed	Response to grazing	Ungrazed	Grazed	Response to grazing
Artemisia frigida	-	-		97	100	
Chrysopsis hirsutissima	62	27	Decrease	53	45	Decrease
Lygodesmia juncea	17	1	Decrease	40	3	Decrease
Phlox hoodii	-	-		37	40	
Selaginella densa	-	-		37	50	
Artemisia biennis	20	1	Decrease	28	3	Decrease
Cerastium arvense	89	120		25	18	
Rosa spp.	12	12		23	18	
Comandra pallida	34	-		23	0	
Sphaeralcea coccinea	14	1	Decrease	15	5	Decrease
Androsace puberulenta	3	0		3	0	
Anemone patens wolfgangiana	5	18	Increase	12	25	Increase
Arabis holboellii retrofracta	1	1		5	3	
Arabis spp.	1	1		5	3	
Artemisia ludoviciana gnaphalodes	Tr.	0		2	0	
Aster spp.	1	0		3	0	
Astragalus spp.	Tr.	0		2	0	
Campanula rotundifolia	8	5		2	3	
Chamaerhodos nuttallii	2	7		2	8	
Equisetum spp.	1	0		3	0	
Gaura coccinea	0	1		0	3	
Geum triflorum	0	22	Increase	0	13	Increase
Haplopappus spinulosus	6	2		12	8	
Hymenoxys richardsonii	7	0	Decrease	7	0	Decrease
Liatris punctata	4	0	Decrease	12	0	Decrease
Linum compactum	0	3		-	8	

TABLE 14 (Continued)

Species	DENSITY: No. of plants per 20 sq. metres			PERCENTAGE FREQUENCY		
	Ungrazed	Grazed	Response to grazing	Ungrazed	Grazed	Response to grazing
Oxytropis macounii	1	2		3	5	
Petalostemum purpureum	3	0		7	0	
Potentilla spp.	1	0		3	0	
Potentilla strigosa	6	15		13	30	
Psoralea lanceolata	0	1		0	3	
Symphoricarpos occidentalis	Tr.	6		2	8	
Thermopsis rhombifolia	Tr.	0		2	0	
Vicia spp.	Tr.	0		2	0	

This species is also frequent on the Biggar gravelly soils and the Asquith sands (Plate 12).

Grazed sites

On the grazed sites *Stipa comata* and *Bouteloua gracilis* are still dominant although the former species is considerably reduced in density (Table 13). *Calamovilfa longifolia*, which was observed to be quite palatable, is sparsely represented. *Koeleria cristata* appeared to be little affected by the grazing. Throughout this work it was constantly observed that this species suffered less drastically from grazing than did other erect grasses. On these dune sand grasslands extreme drought conditions are frequently experienced. During these periods there is considerable killing and the ability of species to establish from buried viable seed is critical. Weaver and Albertson (1944) record that *K. cristata* is greatly harmed by drought, and generally has a greater instability and a shorter life span than most other grasses. Coupland (1950) reports that the species reseeds bared areas quickly. It is a prolific seeder. Tests carried out during the present study showed the germination to be 66.0 percent.

Table 13 shows that the grasses and the sedges together contributed only 23 percent of the total vegetation.

The percentage basal cover of *Artemisia frigida* is twice that of its cover on the relict sites (Plate 13). *Lygodesmia juncea*, a deep rooting drought resistant Composite, was observed to be grazed by cattle and is considerably reduced in abundance on the grazed sites (Table 14). *Artemisia biennis*,

which is quite frequent on the relict sites, was present in only three percent of the quadrats. This is in contrast to the behaviour of the species on the Biggar soils where it is more frequent on grazed sites. The tall flowering stem of this species aids in a wide scattering of its disseminules. Geum triflorum and Potentilla strigosa are again more frequent on the grazed sites. G. triflorum forms dense colonies in small depressions as it does on other soil types. The species is spreading mainly by vegetative reproduction (Plate 8). Anemone patens wolfgangiana is not as abundant as on the Biggar and Weyburn soils. This species is not frequent in the drier habitats of the mixed prairie to the south.

A number of legumes were listed from these sites, Vicia spp., Thermopsis rhombifolia, Psoralea lanceolata, Petalostemum purpureum, Oxytropis macounii, Astragalus spp., but not one is in great abundance on either the grazed or the ungrazed sites (Table 14). There is a need of research into the question of which are the most valuable of the native pasture legumes in this area and on how best to encourage their growth. From the limited data of this study it would appear that Astragalus flexuosus and Thermopsis rhombifolia are the most widespread. The latter species is avoided to some extent by cattle.

GRASSLAND COMMUNITIES

The foregoing classification of grasslands on the basis of soil Associations obscures differences between the major

grassland communities of the area. In this section these differences are discussed and the grasslands are classified according to the dominant species.

Stipa - Bouteloua Faciation

The Stipa - Bouteloua faciation is restricted in the area of the present study entirely to soil developed on dune sands. Stipa comata is the principal dominant. S. spartea curtiseta, which is of considerable abundance in other grasslands of the area, is not important in the faciation. Bouteloua gracilis, the co-dominant, increases in abundance where grazed and it was observed that on the protected sites that had had some degree of disturbance B. gracilis comprises a higher percentage of the total vegetation than on the completely undisturbed areas. It is probable that this species was of less importance in the biome than would appear from a study of the data presented. The data recorded from the study of these grasslands is presented in Tables 13 and 14 and have already been discussed in the foregoing section.

Festuca scabrella Consociation

The Festuca scabrella consociation is restricted to the Biggar soils overlying outwash gravels. These soils are very free draining and moisture relations appear to be favorable to deep-rooting perennial species (Tables 15 and 16). Moss and Campbell (1947) in describing the Fescue grasslands of Alberta record that on the poorer sites, such as stony soils and dry

TABLE 15

Vegetation of the Festuca scabrella Consociation; data from a point-transect survey of 2 relict and 2 grazed sites.

Species	PERCENTAGE BASAL COVER		PERCENTAGE COMPOSITION	
	Ungrazed	Grazed	Ungrazed	Grazed
Festuca scabrella	3.38	0.33	20.2	1.5
Stipa spartea curtiseta	0.97	0.20	5.8	0.9
Koeleria cristata	0.71	2.81	4.3	12.5
Helictotrichon hookeri	0.46	0.05	2.8	0.2
Agropyron spp.	0.32	0.40	1.9	1.8
Festuca ovina	0.08	0.00	0.5	0.0
Bouteloua gracilis	0.00	0.79	0.0	3.5
Total grasses	5.92	4.57	35.4	20.3
Carex obtusata	0.91	0.45	5.4	2.0
Carex stenophylla enervis	0.52	1.52	3.1	6.7
Carex pensylvanica digyna	0.00	1.00	0.0	4.4
Total sedges	1.43	2.97	8.6	13.2
Artemisia frigida	0.88	3.77	5.3	16.7
Phlox hoodii	0.05	0.96	0.3	4.3
Other forbs and shrubs	8.42	10.27	50.4	45.6
Total forbs and shrubs	9.35	14.99	56.0	66.5
Total vegetation	16.70	22.53	100.0	100.0

TABLE 16

Shrubs and forbs of the <u>Festuca scabrella</u> Consociation; data from metre-quadrat counts on 2 relict and 2 grazed sites. Principal species are listed in order of their decreasing frequency on the ungrazed sites.

Species	DENSITY: No. of plants per 20 sq. metres			PERCENTAGE FREQUENCY		
	Ungrazed	Grazed	Response to grazing	Ungrazed	Grazed	Response to grazing
Solidago missouriensis	1479	764	Decrease	80	65	Decrease
Achillea lanulosa	106	378		68	55	
Cerastium arvense	268	300		65	60	
Rosa spp.	36	37		63	45	
Aster ericoides	333	306		60	58	
Artemisia ludoviciana gnaphalodes	-	-		58	20	Decrease
Selaginella densa	-	-		53	73	
Anemone patens wolfgangiana	21	109	Increase	48	85	Increase
Artemisia frigida	-	-		45	78	Increase
Solidago rigida	36	18		30	5	Decrease
Heuchera richardsonii	5	2		18	8	
Androsace puberulenta	6	10		13	20	
Antennaria campestris	-	-		13	3	
Antennaria microphylla	-	-		5	30	Increase
Arabis spp.	0	1		0	3	
Artemisia biennis	10	30	Increase	13	43	Increase
Artemisia ludoviciana pabularis	6	0		3	0	
Aster spp.	0	30		0	5	
Astragalus spp.	4	8		8	10	
Campanula rotundifolia	1	17		5	8	
Comandra pallida	8	48	Increase	15	58	Increase
Erigeron glabbelus	1	12	Increase	3	8	
Erigeron spp.	0	1		0	5	
Gaillardia aristata	0	1		0	3	
Galium boreale	12	33	Increase	15	30	Increase
Gentiana strictiflora	1	1		5	3	

TABLE 16 (Continued)

Species	DENSITY: No. of plants per 20 sq. metres			PERCENTAGE FREQUENCY		
	Ungrazed	Grazed	Response to grazing	Ungrazed	Grazed	Response to grazing
Geum triflorum	5	91	Increase	15	45	Increase
Orthocarpus luteus	9	96	Increase	13	15	
Oxytropis spp.	0	1		0	5	
Phlox hoodii	-	-		5	35	Increase
Potentilla camporum	5	1		10	5	
Potentilla strigosa	4	16		10	38	Increase
Solidago decumbens oreophila	5	2		13	5	
Solidago dumetorum	1	2		3	5	
Sphaeralcea coccinea	0	1		0	5	
Thermopsis rhombifolia	1	3		3	10	
Vicia sparsifolia	0	1		0	3	
Viola adunca	25	10		8	5	

slopes, F. scabrella is quickly replaced under grazing and mowing conditions by such species as Stipa spartea curtiseta, Koeleria cristata, and species of Carex. On some of their sites F. scabrella was eliminated by heavy grazing. On the sites of the present survey Festuca scabrella, while not eliminated by grazing, is considerably reduced. There is an associated increase of Koeleria cristata and Bouteloua gracilis.

In areas where the extreme drainage conditions of the Biggar soils are ameliorated to some extent by a slightly heavier subsoil Stipa spartea curtiseta, Agropyron dasystachyum and A. smithii are of increased importance and dominate some sites. There is a critical balance between dominance by Festuca scabrella and dominance by Stipa spartea curtiseta. Among the factors controlling this balance are the nature of the subsoil and the depth of the water table. The difference in rooting depth of the two species has been noted. Different forb populations are associated with these two grasses. Where F. scabrella is dominant Solidago missouriensis, S. rigida, Aster ericoides, and Cerastium arvense are associated species. Where S. spartea curtiseta dominates other forbs are more abundant, notably Campanula rotundifolia, Anemone patens wolfgangiana, Comandra pallida, Galium boreale, Erigeron caespitosus, Gaillardia aristata and Chrysopsis hirsutissima. Artemisia frigida and Phlox hoodii are most abundant on these soils when associated with S. spartea curtiseta.

Carex stenophylla enervis is of less importance than in other communities and it is C. obtusata that is the principal

sedge (Table 15). The latter species is not important in any other community. The relative abundance of the two sedges is reversed on the grazed sites. Carex pensylvanica digyna was not recorded in the dense mat of Festuca scabrella foliage which covered the relict grassland, but is quite abundant in the pastures. The mat, composed of this and previous years' growth, allows little light to reach the low-growing species. When this mat is removed by the grazing animal considerable changes occur in the botanical composition of the sward (Table 16).

Agropyron - Stipa Faciation

The Agropyron-Stipa faciation occupies the coarse-textured gently rolling Weyburn soils and most Elstow soils. Agropyron dasystachyum, A. smithii, and Stipa spartea curtiseta, are the dominant species (Table 17). All the sites are on soils of light-loam to clay-loam top soils overlying clay at less than 20 inches. The only Elstow site where this faciation does not occur is on lighter soil with a sandy-clay-loam lower sub-soil. This site is dominated by Stipa spartea curtiseta, the species of Agropyron being less abundant than in the faciation. Bouteloua gracilis and Koeleria cristata are the principal sub-dominant grasses. Carex stenophylla enervis is more abundant in this faciation than in the two communities already described, making up 25 percent of the vegetation of the pastures. The cover of the forbs and shrubs is half that of the cover in other communities. The prairie roses are abundant. Artemisia frigida makes up 20 percent of the vegetation. Cerastium arvense is

TABLE 17

Vegetation of the Agropyron-Stipa Faciation; data from a point-transect survey of 7 relict and 8 grazed sites. *

Species	PERCENTAGE BASAL COVER		PERCENTAGE COMPOSITION	
	Ungrazed	Grazed	Ungrazed	Grazed
Agropyron spp.	2.50	0.91	17.8	3.7
Stipa spartea curtiseta	1.86	0.37	13.2	1.5
Bouteloua gracilis	0.80	2.50	5.7	10.2
Koeleria cristata	0.50	0.43	3.6	1.8
Festuca scabrella	0.37	0.01	2.6	Tr.
Stipa comata	0.19	0.01	1.4	Tr.
Stipa viridula	0.16	0.00	1.1	0.0
Poa secunda	0.09	0.01	0.6	Tr.
Agrostis spp.	0.01	0.00	0.1	0.0
Muhlenbergia richardsonis	0.00	0.03	0.0	0.1
Total grasses	6.50	4.27	46.3	17.4
Carex stenophylla enervis	2.50	6.29	17.8	25.6
Carex pensylvanica digyna	0.34	0.10	2.4	0.4
Carex lasiocarpa americana	0.01	0.00	0.1	0.0
Carex obtusata	0.00	0.01	0.0	Tr.
Total sedges	2.86	6.39	20.4	26.0
Artemisia frigida	2.87	12.56	20.4	51.2
Phlox hoodii	0.04	0.62	0.3	2.5
Other forbs and shrubs	1.77	0.68	12.6	2.8
Total forbs and shrubs	4.68	13.87	33.3	56.5
Total vegetation	14.04	24.53	100.0	100.0

* Tr. = trace

locally very abundant (Table 18).

On the grazed sites Agropyron dasystachyum, A. smithii and Stipa spartea curtiseta are less abundant and are replaced by the less valuable forage species, Bouteloua gracilis. Data obtained by Clarke et al.(1942), during a study of the carrying capacity of native pastures in Saskatchewan and Alberta, have shown that Agropyron smithii and Stipa spartea curtiseta are considerably more productive than Bouteloua gracilis per unit area of basal cover. No figures were given for A. dasystachyum. The total grass cover is less on the grazed sites, but because of the greater abundance of Carex stenophylla and Artemisia frigida the vegetational cover is considerably more than on the relict grasslands. Whereas on the relict sites grasses make up almost half of the vegetative cover, on the grazed sites they contribute only 17 percent, of which more than half is Bouteloua gracilis. Selaginella densa and Phlox hoodii have increased considerably under grazing and the delicate silver-leaved stems of Antennaria microphylla have colonised some bared areas (Plate 14).

Stipa spartea curtiseta Consociation

From the foregoing it will be realized that the association of soil type with plant community in the area is very strong. It is only in the case of the Stipa spartea curtiseta consociation that this relationship breaks down. This community dominates sites on all the soils with the exception of the dune sands. All Asquith soils are so occupied; S. comata is also

TABLE 18

Shrubs and forbs of the Agropyron - Stipa Faciation; data from metre-quadrat counts on 7 relict and 8 grazed sites. Principal species are listed in order of their decreasing frequency on the ungrazed sites.

Species	DENSITY: No. of plants per 20 sq. metres			PERCENTAGE FREQUENCY		
	Ungrazed	Grazed	Response to grazing	Ungrazed	Grazed	Response to grazing
Artemisia frigida	-	-		78	96	Increase
Rosa spp.	44	19		27	23	
Aster ericoides	67	3	Decrease	20	6	Decrease
Selaginella densa	-	-		19	38	Increase
Cerastium arvense	252	12	Decrease	18	4	Decrease
Achillea lanulosa	38	6	Decrease	16	3	Decrease
Solidago missouriensis	32	80		14	19	
Artemisia ludoviciana gnaphalodes	-	-		14	5	
Anemone patens wolfgangiana	12	17		12	29	
Comandra pallida	10	6		11	6	
Allium textile	-	Tr.		0	1	
Androsace puberulenta	2	13		6	10	
Antennaria campestris	-	-		1	1	
Antennaria microphylla	-	-		1	8	Increase
Arabis spp.	0	1		0	3	
Artemisia biennis	Tr.	0		1	0	
Artemisia ludoviciana pabularis	4	0		2	0	
Aster spp.	20	Tr.	Decrease	6	1	Decrease
Aster coerulescens	0	1		0	1	
Astragalus flexuosus	Tr.	0		1	0	
Astragalus spp.	Tr.	Tr.		1	1	
Campanula rotundifolia	0	4		0	2	
Chenopodium spp.	1	Tr.		5	1	
Chrysopsis hirsutissima	0	1		0	2	
Galium boreale	9	10		5	3	
Geum aleppicum strictum	0	Tr.		0	1	

TABLE 18 (Continued)

Species	DENSITY: No. of plants per 20 sq. metres			PERCENTAGE FREQUENCY		
	Ungrazed	Grazed	Response to grazing	Ungrazed	Grazed	Response to grazing
Geum triflorum	5	7		6	8	
Grindelia squarrosa quasiperennis	0	Tr.		0	2	
Gutierrezia diversifolia	1	1		1	3	
Heuchera richardsonii	1	1		2	3	
Lepidium densiflorum	1	14	Increase	2	5	Increase
Orthocarpus luteus	Tr.	Tr.		1	1	
Pentstemon spp.	0	Tr.		0	1	
Phlox hoodii	-	-		0	16	Increase
Polygonum aviculare	0	Tr.		0	1	
Potentilla camporum	Tr.	2		1	3	
Potentilla strigosa	17	7		4	15	
Potentilla spp.	0	4		0	7	
Salsola kali tenuifolia	Tr.	Tr.		1	1	
Scirpus spp.	0	Tr.		0	1	
Solidago rigida	1	0		1	0	
Solidago spp.	3	0		4	0	
Sphaeralcea coccinea	Tr.	Tr.		1	1	
Symphoricarpos occidentalis	0	1		0	2	
Taraxacum spp.	0	Tr.		0	1	
Thermopsis rhombifolia	2	Tr.		4	2	

very important here. The heavier Weyburn soils, the most steeply rolling of the coarse-textured Weyburn soils, the finest textured of the Biggar soils, and the most droughty Elstow soils, all are occupied by the consociation. This is the major community of the area and probably the one most in equilibrium with the climate.

Koeleria cristata is associated with S. spartea curtiseta and is of considerable importance on all sites. Carex stenophylla enervis and Artemisia frigida together comprise over 60 percent of the total basal cover (Tables 19 and 20). The cover of grasses and sedges together, and the cover of all vegetation, is greater than in any other community. Artemisia frigida and Anemone patens wolfgangiana are very abundant. A legume, Astragalus flexuosus, occurred in 11 percent of the quadrats. Solidago missouriensis is widespread and abundant. Galium boreale is locally abundant, often in association with Cerastium arvense.

On the grazed sites Stipa spartea curtiseta is less abundant, but this is not so of another bunch grass, Koeleria cristata. Bouteloua gracilis is again more important on the grazed sites, but in this instance there is no corresponding increase in Carex stenophylla enervis. Astragalus flexuosus, one of the few legumes that is at all widespread on these grasslands, is hardly to be found in pasture. The greater abundance of the rosette forb, Geum triflorum, will be noted (Table 20). Artemisia frigida

TABLE 19

Vegetation of the <u>Stipa spartea curtiseta</u> Consociation; data from a point-transect survey of 7 relict and 10 grazed sites.

Species	PERCENTAGE BASAL COVER		PERCENTAGE COMPOSITION	
	Ungrazed	Grazed	Ungrazed	Grazed
Stipa spartea curtiseta	2.91	1.08	15.5	4.2
Koeleria cristata	1.21	1.18	6.4	4.6
Bouteloua gracilis	1.09	2.31	5.8	9.0
Agropyron spp.	0.61	0.48	3.2	1.9
Festuca scabrella	0.47	0.04	2.5	0.2
Stipa comata	0.11	0.14	0.6	0.5
Poa spp.	0.06	0.03	0.3	0.1
Total grasses	6.47	5.27	34.4	20.6
Carex stenophylla enervis	3.47	3.63	18.4	14.2
Carex pensylvanica digyna	0.19	0.22	1.0	0.9
Carex praegracilis	0.01	0.00	0.1	0.0
Carex obtusata	0.00	0.01	0.0	Tr.
Total sedges	3.67	3.86	19.5	15.1
Artemisia frigida	6.04	11.98	32.1	46.8
Phlox hoodii	0.66	2.13	3.5	8.3
Other forbs and shrubs	1.97	2.35	10.5	9.2
Total forbs and shrubs	8.67	16.46	46.1	64.3
Total vegetation	18.81	25.59	100.0	100.0

TABLE 20

Shrubs and forbs of the Stipa spartea curtiseta Consociation; data from metre-quadrat counts on 7 relict and 10 grazed sites. Principal species are listed in order of their decreasing frequency on the ungrazed sites.

Species	DENSITY: No. of plants per 20 sq. metres			PERCENTAGE FREQUENCY		
	Ungrazed	Grazed	Response to grazing	Ungrazed	Grazed	Response to grazing
Artemisia frigida	-	-		80	94	Increase
Anemone patens wolfgangiana	86	72		53	53	
Selaginella densa	-	-		44	46	
Rosa spp.	41	23		40	26	Decrease
Solidago missouriensis	126	98		31	25	
Comandra pallida	19	7	Decrease	17	10	Decrease
Achillea lanulosa	25	15		14	7	
Phlox hoodii	-	-		14	31	
Astragalus flexuosus	8	1	Decrease	11	2	Decrease
Artemisia ludoviciana gnaphalodes	-	-		11	11	
Galium boreale	65	36		11	8	
Potentilla strigosa	5	45	Increase	11	39	Increase
Androsace puberulenta	4	4		9	12	
Antennaria campestris	-	-		1	0	
Antennaria microphylla	-	-		4	7	
Arabis spp.	Tr.	Tr.		1	2	
Arabis holboellii retrofracta	Tr.	0		1	0	
Artemisia biennis	1	2		4	5	
Artemisia ludoviciana pabularis	1	0		1	0	
Aster ericoides	46	8	Decrease	9	9	
Aster spp.	Tr.	2		1	1	
Astragalus spp.	1	1		2	4	
Campanula rotundifolia	3	6		4	4	
Capsella bursa-pastoris	0	Tr.		0	1	
Cerastium arvense	16	11		8	6	
Chenopodium spp.	Tr.	Tr.		1	1	
Chrysopsis hirsutissima	3	2		6	8	

TABLE 20 (Continued)

Species	DENSITY: No. of plants per 20 sq. metres			PERCENTAGE FREQUENCY		
	Ungrazed	Grazed	Response to grazing	Ungrazed	Grazed	Response to grazing
Equisetum spp.	1	0		Tr.	0	
Erigeron caespitosus	7	5		6	1	
Erigeron spp.	Tr.	2		1	4	
Gaillardia aristata	3	Tr.		1	1	
Geum triflorum	7	62	Increase	9	18	Increase
Grindelia squarrosa quasiperennis	0	6		0	3	
Gutierrezia diversifolia	1	8		3	12	
Haplopappus spinulosus	2	1		1	3	
Heuchera richardsonii	2	1		4	2	
Lepidium densiflorum	Tr.	Tr.		1	Tr.	
Liatris punctata	0	Tr.		0	2	
Linum lewisii	Tr.	Tr.		1	1	
Lygodesmia juncea	1	1		1	2	
Oenothera spp.	0	Tr.		0	Tr.	
Orthocarpus luteus	1	1		2	1	
Oxytropis spp.	0	Tr.		0	Tr.	
Potentilla camporum	1	4		4	7	
Potentilla spp.	13	15		9	23	
Psoralea argophylla	0	Tr.		0	Tr.	
Solidago rigida	Tr.	Tr.		Tr.	Tr.	
Solidago spp.	0	1		0	1	
Sphaeralcea coccinea	6	13		3	10	
Symphoricarpos occidentalis	0	1		0	Tr.	
Thermopsis rhombifolia	Tr.	2		Tr.	7	
Vicia sparsifolia	Tr.	0		1	0	

comprises almost 50 percent of the basal cover.

ROOT WEIGHTS

In the general sampling procedure soil horizons from eight cores were bulked and made up one sample. To determine the variability within these bulked samples two grasses were studied on Asquith soils. In this case the individual horizon samples were not bulked but were washed and weighed separately (Appendix 5). Because of the large number of samples involved the ash weights could not be obtained; however, because of the smallness of the individual samples, the washing technique was more efficient and any error occasioned by the attachment of soil particles to the fine roots was minimized. Appendix 5 in conjunction with the appropriate table from Paterson (1939) shows that to demonstrate a 15 percent difference between grasses ($P = 0.05$) 23 to 31 samples are necessary when studying the 0- to 2- inch soil horizon. If concerned with root weights from the whole cores (0-24 inches) only seven samples are needed. There is a very high coefficient of variability in the samples from the 0- to 2- inch horizon. In this experiment a significant difference is shown between the root weights of the two grasses in the 0- to 2- inch horizon. The root weights for <u>Stipa spartea curtiseta</u> are significantly higher than for <u>Bouteloua gracilis</u> (Appendix 5). In the total core samples the coefficient of variability was much lower. No differences were shown. As eight samples were taken any difference between grasses must be considerably below 15 percent.

The above information was not available until after laboratory work had commenced in the winter, and therefore could not be applied to the general sampling on eight Asquith and one Elstow soils. The methods of this latter study have been outlined. The samples were bulked, ash weights were subtracted from dry weights and the values so obtained were used in the calculations (Appendix 6).

With a single exception no differences could be shown between root weights from grazed as opposed to ungrazed sites. This exception was obtained from a comparison of the root weights of Bouteloua gracilis; the weight obtained from the 0- to 2- inch soil layer was greater on the ungrazed than on the grazed sites. This result was obtained from samples of four grazed and four ungrazed sites on strictly comparable soils (Appendix 7). There are indications that the root weights of the grasses are greater in the 0- to 2- inch horizon of Elstow soils than in the lighter Asquith soils and the root weights beneath Artemisia frigida are greater than beneath the grasses, however the number of replications was insufficient to verify this. Between 32 and 49 percent of the weight of grass roots to a depth of 24 inches was found in the 0- to 2- inch soil layer. The roots in twice that volume of soil, the 2- to 6- inch horizon, were only 22 to 30 percent of the total.

Under the conditons of semi-aridity prevailing in the area the core-sampling technique was found unsuitable for the examination of the roots of any but the mat-forming grasses. Bunch grasses may not be sampled at random and differences in

the diameter of their crowns reflect a variation in root production which adds to the variation within samples. However, the standard errors recorded for the bunch grasses are not greatly in excess of the standard errors for *Bouteloua gracilis* (Appendix 6). Grazing is not a uniform treatment, each site (replicate) being grazed by different stock at a different grazing intensity. Because of this the standard errors of the ungrazed sites were expected to be lower than those of the grazed sites, but this was not borne out by the results.

The washing technique was satisfactory; the use of a fine screen, a number of decantations, and the procedure of ashing the samples, eliminated a number of errors inherent in the usual monolith washing methods. As a large number of small samples may be dealt with the results are adaptable to a statistical analysis. The main criticism of the method must be that no idea can be formed by the investigator of the rooting habit of the species. Only the root weights present in various soil horizons are obtained. From this point of view the monolith method, as used by Weaver and Darland (1949), is superior.

VEGETATION OF CATTLE PATHS

The vegetation of the cattle paths was observed to be very different from that of the surrounding pasture (Plate 15). A point-transect survey of the vegetation of paths was made on two sites (Table 21). The table gives only the composition of the vegetation; the density of the path vegetation was much less than that of the remainder of the pasture. *Stipa comata*, *S. spartea curtiseta* and *Carex stenophylla enervis* are able to

TABLE 21

Percentage composition of the vegetation of cattle-paths compared with that of the remainder of the pasture. Data from 2 sites on different soils.

Species	DUNE SANDS		WEYBURN LOAM	
	Pasture	Cattle path	Pasture	Cattle path
Agropyron spp.	-	-	0.00	3.51
Bouteloua gracilis	11.10	15.87	4.80	0.00
Calamovilfa longifolia	0.31	0.00	-	-
Koeleria cristata	2.46	9.52	2.01	0.88
Poa spp.	-	-	0.25	0.00
Stipa spp.	5.86	28.57	6.03	35.97
Total grasses	19.74	53.96	13.08	40.36
Carex obtusata	-	-	0.49	0.00
Carex pensylvanica digyna	-	-	0.74	0.00
Carex stenophylla enervis	7.70	38.09	9.56	53.51
Total sedges	7.70	38.09	10.79	53.51
Artemisia frigida	69.47	4.76	59.71	6.14
Phlox hoodii	1.84	0.00	10.08	0.00
Other forbs and shrubs	1.21	3.18	6.28	0.00
Total forbs and shrubs	72.52	7.94	76.07	6.14
Total vegetation	100.00	100.00	100.00	100.00

withstand the extreme conditions better than other species. Artemisia frigida is very much reduced and Phlox hoodii is entirely absent from the paths. The vegetation is much more restricted than that of the pasture and the grasses and sedges make up over 90 percent of the vegetation.

Bates (1935) found that the soils of the paths receive increased moisture because they are lower than the surrounding soils, and the vegetation receives increased light because of the opening of the plant cover. In his study these factors were of minor importance only. The paths also receive more dung and urine than the pasture and are at least in some instances more heavily grazed. Bates considers that the chief factor in the production of the footpath socies from the grassland community is the effect of treading and puddling. This exerts a selective influence favouring those species with a cryophytic life form, and those adapted by leaf and stem structure to withstand the injury of treading. Treading increases the density of the soil of the path and this has a secondary influence on soil temperature and moisture. Under dry conditions where no puddling occurs treading alone produces little change in vegetation. Bates describes a zonation of the vegetation of the paths. Towards the edges of the paths the treading became progressively less and various zones dominated by one or more species were in evidence. No such zonation was observed in the present study area.

The reduced abundance, on the paths, of Artemisia frigida, a most pernicious pasture weed, is of some significance. Any

factor or group of factors which will, under grazing conditions, favour the spread of grasses relative to the spread of _A. frigida_ is worthy of study.

BURIED VIABLE SEEDS

The colonisation of bared areas is very important in grasslands that are subjected to heavy grazing and especially is this so in semi-arid climates. Many of the smaller bared areas are quickly invaded by the vegetative spread of rhizomatous species and by the tillering of mat grasses (Plate 6) but in these areas and more especially in the larger bared areas there is colonisation by seedling establishment.

In order to obtain a measure of the numbers of buried viable grass and forb seeds in these grassland soils, soil samples were obtained and the seeds germinated by the methods previously outlined. Three paired sites and an abandoned field were sampled, all on coarse-textured soils. The reported history of the abandoned field is that it was ploughed in 1915. For 30 years there have been no cultivations and the field has been grazed by cattle for the last 20 years. A point-transect survey of the field showed that _Artemisia frigida_ made up 80 percent of the total vegetation while the two principal grasses, _Stipa comata_ and _Bouteloua gracilis_, made up 4.4 and 3.5 percent, respectively.

The number of viable seeds per unit volume of soil was greatest in the samples from the abandoned field (Table 22). The number present in samples from the grazed sites was not only

TABLE 22

Numbers of viable seeds obtained from samples each of 62 2-inch diameter cores 2 inches deep, taken at random on seven sites.

Number of sites sampled	Management	NO. OF VIABLE SEEDS IN 390 CU. INS. OF SOIL		
		Grasses	Forbs	Total
3	Ungrazed	34	31	65
3	Grazed	6	24	30
1	Abandoned arable. Now grazed	26	53	79

smaller than from the ungrazed sites but of these seeds a higher percentage were those of forbs. Not only does heavy grazing restrict the seeding of the valuable pasture species, but certain forbs, notably *Artemisia frigida*, are able to take advantage of the reduction in competition from the climax dominants and these less valuable species are able to set more seed than they may do in competition in undisturbed grassland. Under grazing conditions the grass able to set the most seed was *Bouteloua gracilis*.

Milton (1943), working in England, found the greatest concentrations of viable seeds in the wetter soils, in his case heavy clays. He postulated that deficient aeration and lower soil temperatures under such conditions may have a preservative effect on the vitality of seeds. In view of these findings it is possible that a larger number of viable seeds would have been obtained from the less droughty soils in this survey area. Nevertheless, the abandoned field soils containing the highest number of viable seeds are developed on dune sands and in consequence are the most droughty. It would appear that other factors are equally important, possibly the periodicity of conditions favorable to germination are less frequent on the dune sands under the prevailing conditions of low precipitation and high evaporation.

CONCLUSIONS

Within the study area climatic conditions are relatively uniform and the main controlling influence on the composition of

the plant communities is that of soil. This influence is exerted mainly through the availability of soil moisture. Most of the communities are restricted to one particular soil Association; however the Stipa spartea curtiseta consociation is dominant on a number of soils and probably is the community best adapted to the climate. Communities of other climatic regions extend into the area on soils that simulate the conditions of their native region. The Fescue Association extends southward into the area on soils developed on outwash gravels where subsoil moisture conditions are favourable to the deep-rooting dominants. The Stipa-Bouteloua faciation extends northward into the area on the xeric habitat of the dune sands.

The flora of these grasslands is considerably altered by grazing. With the exception of Koeleria cristata, which dominates the pastures on the gravelly Biggar soils, all the erect perennial grasses that are present in any abundance are reduced by grazing. Bouteloua gracilis, a mat-grass of little forage value, increases in abundance in pastures. The value as forage of the dominant grasses of the study area has been assessed in mixed prairie 200 miles to the south. These grasses are readily eaten by stock (Clark and Tisdale 1945). B. gracilis is less productive (Clark et al. 1942) and of less nutritive value (Clarke and Tisdale 1945) than the dominant erect grasses. By heavy and continuous grazing the grasslands are reduced to extremely unproductive pastures. Although the basal cover of the vegetation is generally greater on the grazed sites than on the ungrazed sites, the valuable erect perennial grasses are lost

and species such as *B. gracilis*, *Carex stenophylla enervis*, and *Artemisia frigida* make up most of the cover. *C. stenophylla enervis*,which is the principal sedge of these grasslands and contributes a high percentage of the vegetation of most grazed sites,is unproductive and is of little value as forage. *Artemisia frigida* occurred in more than 70 percent of the quadrats on relict grassland and increases in abundance under grazing. In spite of its great abundance on the pastures the evidence obtained from a study of the vegetation of the cattle paths suggests that this species is more damaged by excessive trampling than are the erect grasses. Other species whose abundance is indicative of heavy grazing are *Selaginella densa*, *Phlox hoodii*, *Potentilla strigosa*, and *Geum triflorum*. Many other less frequently occurring species may well have considerable indicator value and would probably repay further study.

The number of viable grass seeds present in the soils of some of the pastures is considerably less than the number present in the soils of relict grassland. A grazing management that would allow some seeding of the valuable erect grasses would be advantageous. In addition a rest from grazing,during the spring period of active growth of the most valuable species, would probably be very beneficial. The value of this practice to the pastures of North Dakota has been observed by Sarvis (1923). In the present study area the presence in a pasture of a high percentage of erect perennial grasses is indicative of the skill of the grazier.

SUMMARY

A study of the ecology of the plant species and communities of the ecotone between Fescue grasslands to the north and Canadian mixed prairie to the south was conducted in the vicinity of Saskatoon.

The climate of the area is semi-arid. From May to September evaporation is greatly in excess of the precipitation. The growing season is shortened by a lack of available moisture in mid- and late summer. Winter temperatures are low and the soil remains frozen for four months.

The topography is undulating. The soils are developed on lacustrine and morainic surface deposits. They have been classified as part of the dark brown soil zone of the northern Great Plains. The vegetation of the soil Associations within this major unit is described. The grasslands of the intermediate slope were sampled by the point-transect method. Metre-quadrats were recorded. Both relict and grazed grassland was studied.

The coarse-textured soils of the Weyburn Association are dominated by *Stipa spartea curtiseta*, *Agropyron dasystachyum* and *A. smithii*, and the finer textured soils by *S. spartea curtiseta* and *Koeleria cristata*. Grazing increases the importance of *Bouteloua gracilis*, *Carex stenophylla enervis* and *Artemisia frigida*.

The silty soils of the Elstow Association are more drought resistant. *A. dasystachyum*, *A. smithii* and *S. spartea curtiseta* dominate the relict grassland, whereas *B. gracilis* dominates the

grazed sites. *C. stenophylla enervis* and *A. frigida* contribute over 40 percent of the relict vegetation and increase under grazing.

Soils of the Biggar Association are developed on outwash gravels. They support a dense vegetation dominated by *Festuca scabrella* and *S. spartea curtiseta*. *A. frigida* is less abundant than on other soils. *Koeleria cristata* dominates the grazed sites.

The sandy soils of the Asquith Association are freely draining. Both relict and grazed grasslands are dominated by *Stipa spartea curtiseta* and *Bouteloua gracilis*. *Artemisia frigida* and the prairie roses are abundant and *Selaginella densa* and *Phlox hoodii* are important in preclimax situations.

The relict and grazed grasslands developed on dune sands are dominated by *Stipa comata* and *B. gracilis* which on less droughty soils occupy preclimax habitats. *A. frigida* is very vigorous and abundant.

The botanical composition and the habitat preferences of the various grassland communities of the area are described. The Stipa-Bouteloua faciation is restricted to soils developed on dune sands. The *Festuca scabrella* consociation occupies the Biggar soils developed on outwash gravels. The Agropyron-Stipa faciation dominates the less rolling Weyburn soils and the Elstow soils. The major community of the area is the *Stipa spartea curtiseta* consociation which occurs on all soils with the exception of those developed on dune sands.

The practicability of a core sampling method and a new

root-washing technique, for determining the dry weight of roots beneath the prairie grasses, was assessed. A significant difference was shown between the weight of roots in the 0- to 2-inch soil layers beneath two grasses; Stipa spartea curtiseta produced more roots than Bouteloua gracilis. The weight of roots in the o- to 2- inch layer beneath B. gracilis was significantly greater in ungrazed grassland than in pastures.

The vegetation of cattle paths was studied and was found to be much more restricted than that of the surrounding pastures. Stipa comata, S. spartea curtiseta and Carex stenophylla enervis are best able to withstand the extreme conditions.

The buried viable seed content of soil samples from various sites was measured. The number of seeds obtained was greater from an abandoned field than from relict grassland and greater from relict grassland than from pasture.

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Specimens of some of the plant species mentioned in the text have been lodged in the herbarium of the Dominion Forage Crop Laboratory, Saskatoon.

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Plate 1. Root sampling equipment.

Plate 2. From left to right the beakers hold the roots from a 0- to 2- inch, 2- to 6- inch, 6- to 12- inch, 12- to 18- inch, and 18- to 24- inch soil horizon respectively. The roots have just been transferred from the 60-mesh sieve after the initial washing.

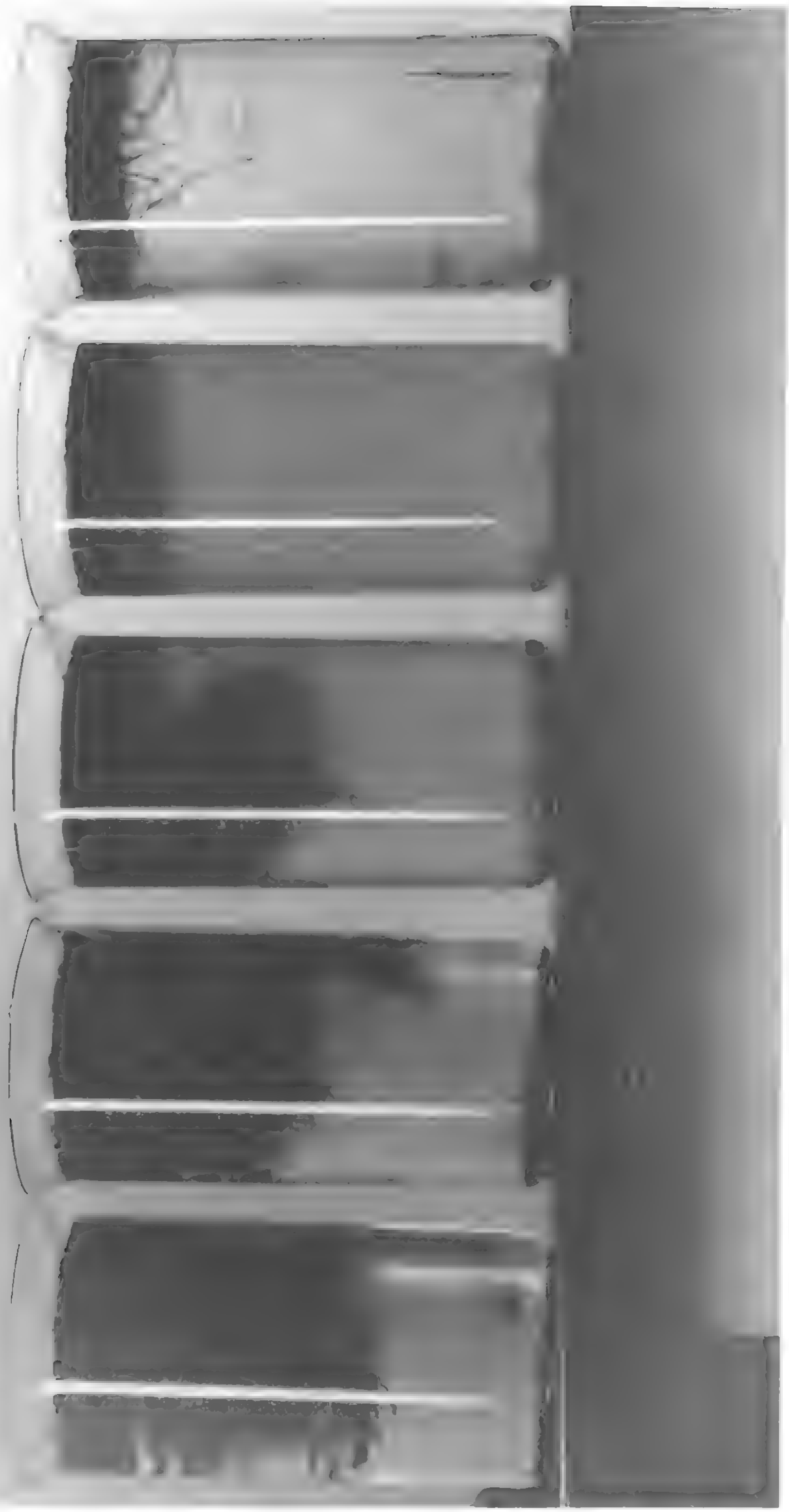

Plate 3. A relict site on Weyburn soil (E 23 - 36 - 4 -W 3).

Plate 4. Selaginella densa and Phlox hoodii colonising an eroding slope ([illegible] 7 - 37 - [illegible] - [illegible]). The coin is a 25 cent piece.

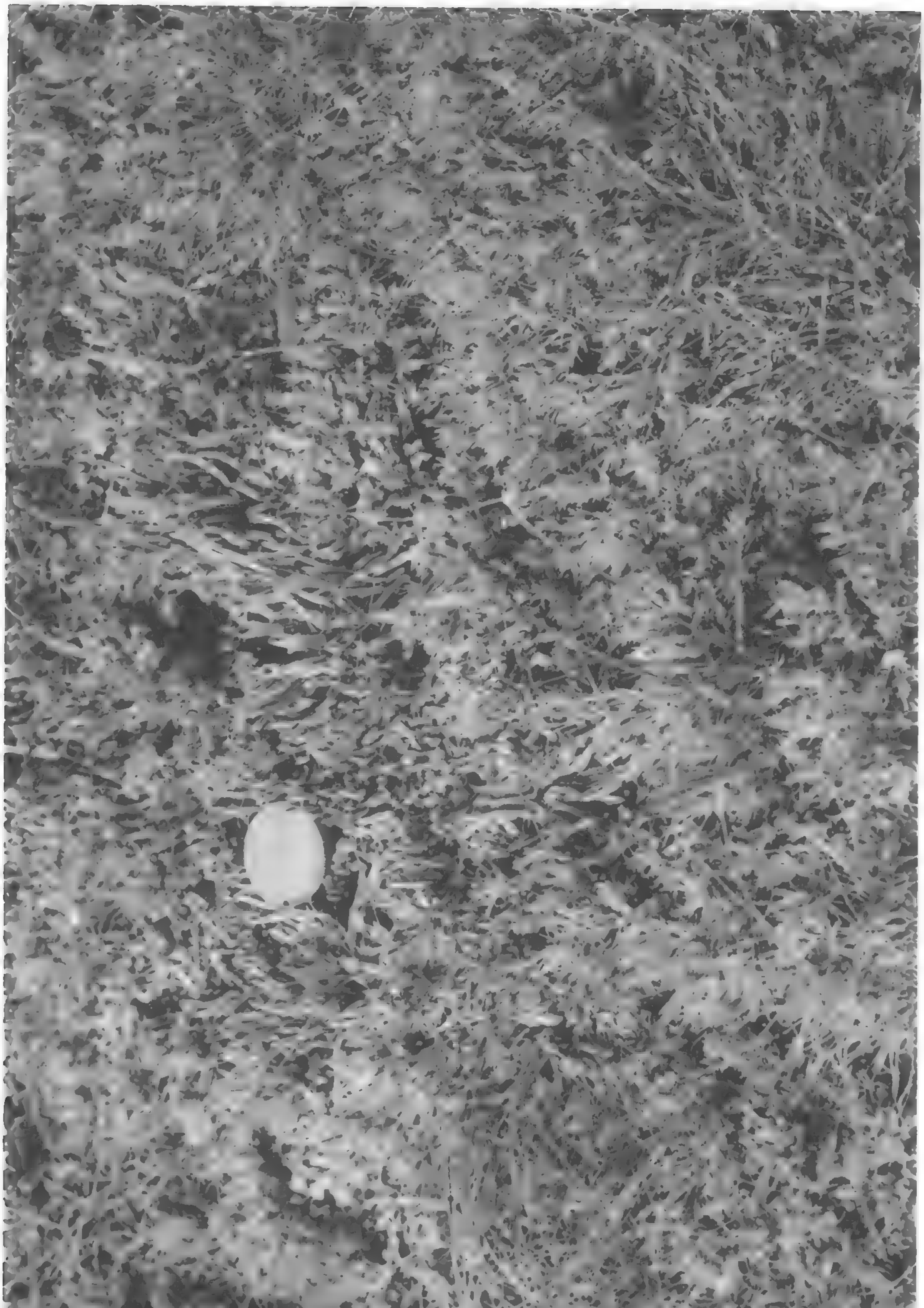

Plate 5. Capping boulders on a Weyburn soil (SE 13 - 37 - 5 - W 3).

Plate 6. Bouteloua gracilis in the background is colonising an area left bare by the death of a large plant of Artemisia frigida. The coin marks the dead crown of A. frigida and the fingers are holding up some of the dead stems (S 11 - 37 - 6 - W 3).

Plate 7. A grazed sward almost entirely composed of *Carex stenophylla enervis*. The grass in the foreground is *Stipa spartea curtiseta* (NW 27 - 36 - 6 - W 3). The coin is a 25 cent piece.

Plate 8. Part of the root systems and underground propagative organs of 1. <u>Solidago missouriensis</u>; 2. <u>Geum triflorum</u>; 3. <u>Comandra pallida</u>.


1
2
3

Plate 9. A paired site on Asquith soil. Sampling was undertaken on either side of, and parallel to, the fence line (E 16 - 36 - 5 - W 3).

Plate 10. Dune topography. A relict site in the foreground. Beyond the fence an abandoned field. Symphoricarpos occidentalis occupies the depression. Note the white sheaths of the flowering culms of Stipa comata in the foreground (NE 7 - 35 - 5 - W 3).

Plate 11. The propagules of 1. _Stipa comata_; 2. _Stipa spartea curtiseta_; 3. _Festuca scabrella_. Note the large pointed seed and strong awn of _Stipa spartea curtiseta_.

Plate 12. Relict grassland on wind-blown sands (S 31 - 35 - 5 - W 3).

Plate 13. Heavily grazed grassland on dune sands. Note the flowering culms of *Artemisia frigida*. This pasture adjoins the site shown in Plate 12 (S 31 - 35 - 5 - W 3).

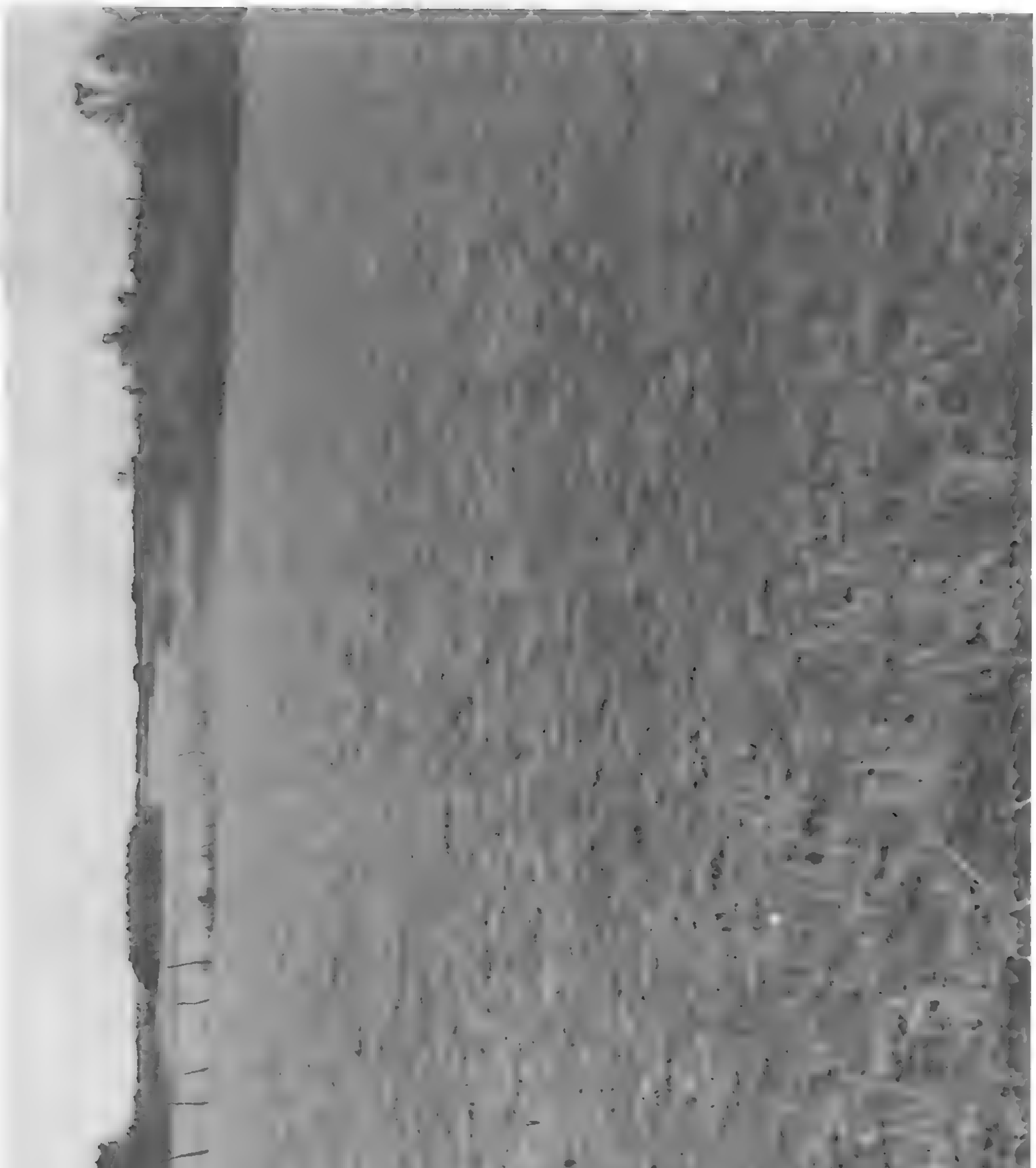

Plate 14. *Antennaria microphylla* in a pasture. Note that the species does not spread beyond the fence line which separates the pasture from relict grassland. (W 17 - 36 - 3 - W 3)

Plate 15. A section of a cattle path showing that _Artemisia frigida_ spreads only to the edge of the path (SW 18 - 37 - 4 - W 3). The ruler is 18 inches long.

Appendix 1. List of species identified.

Grasses

Agropyron dasystachyum (Hook) Scribn.
Agropyron smithii Rydb.
Beckmannia syzigachne (Steud.) Fernald.
Bouteloua gracilis (H.B.K.). Lag. ex Steud.
Calamovilfa longifolia (Hook) Scribn.
Deschampsia caespitosa (L.) Beauv.
Festuca ovina L.
Festuca scabrella Torr.
Helictotrichon hookeri (Scribn.) Henr.
Koeleria cristata (L.) Pers.
Muhlenbergia richardsonis (Trin.) Rydb.
Poa secunda Presl.
Scolochloa festucacea (Willd.) Link.
Stipa comata Trin and Rupr.
Stipa spartea curtiseta Hitchc.
Stipa viridula Trin.

Sedges

Carex lasiocarpa Ehrh. *americana* Fern.
Carex obtusata Lilj.
Carex pensylvanica digyna Boeckl.
Carex praegracilis W. Bott.
Carex stenophylla Wahlenb *enervis* (C.A. Mey.) Kükenth.

Other Species

Achillea lanulosa Nutt.
Allium textile Nels & Macbr.
* *Androsace puberulenta* Rydb.
Anemone patens L. *wolfgangiana* (Bess) Koch.
Antennaria campestris Rydb.
Antennaria microphylla Rydb.
Arabis holboellii Hornem *retrofracta* (Graham) Rydb.
Artemisia biennis Willd.
Artemisia frigida Willd.
Artemisia ludoviciana gnaphalodes (Nutt.) T.&G.
Artemisia ludoviciana pabularis (Nels.) Fern.
* *Aster adsurgens* Greene
Aster coerulescens D.C.
Aster ericoides L.
Astragalus flexuosus Dougl.
Campanula rotundifolia L.

* indicates that the nomenclature is that of Rydberg (1932).

Capsella bursa-pastoris (L.) Medic.
Cerastium arvense L.
Chamaerhodos nuttallii Pickering.
* Chrysopsis hirsutissima Greene.
Comandra pallida A.D.C.
Elaeagnus commutata Bernh.
* Erigeron caespitosus Nutt.
* Erigeron glabbelus Nutt.
* Gaillardia aristata Pursh.
Galium boreale L.
Gaura coccinea Pursh.
* Gentiana strictiflora (Rydb.) A. Nels.
Geum aleppicum strictum (Ait.) Fern.
Geum triflorum Pursh.
Grindelia squarrosa quasiperennis Lunell.
* Gutierrezia diversifolia Greene.
Haplopappus spinulosus (Pursh.) D.C.
Heuchera richardsonnii R.Br.
* Hymenoxys richardsonii (Hook.) Cockerell
* Juncus balticus Willd. montanus Engelm.
Lepidium densiflorum Schrad.
Liatris punctata Hook.
Linum compactum A. Nels.
Linum lewisii Pursh.
Lygodesmia juncea (Pursh.) D.
Orthocarpus luteus Nutt.
* Oxytropis macounii (Greene.) Rydb.
Petalostemum purpureum (Vent.) Rydb.
Phlox hoodii Richardson
Polygonum aviculare L.
* Potentilla camporum Rydb.
* Potentilla strigosa Pall.
Psoralea argophylla Pursh.
Psoralea lanceolata Pursh.
Rosa arkansana Porter
Rosa alcea Greene.
Salsola kali L. tenuifolia Tausch
* Selaginella densa Rydb.
Solidago decumbens Greene. oreophila (Rydb.)
* Solidago dumetorum Lunell.
Solidago missouriensis Nutt.
Solidago rigida L.
Sphaeralcea coccinea (Pursh.) Rydb.
Symphoricarpos occidentalis Hook.
* Thermopsis rhombifolia (Nutt.) Richards
* Vicia sparsifolia Nutt.
Viola adunca Smith.

Appendix 2. Location and description of the sites studied.

Soil Association	Legal description (west 3rd meridian)	Grazed (G) or Ungrazed (U)	Management
Weyburn			
a) coarse textured	W. 29-37-5	U	Road allowance between sections 29 and 30.
	N.E. 26-37-6	G	Grazed by cattle since 1926. Occasionally up to 3 beasts/acre.
	N.W. 7-37-5	U	Road allowance.
	"	G	Grazed by dairy herd, 1 beast/7 acres since 1945.
	N.W. 7-37-4	U	Grazed hard by horses from 1913-20. Since then only occasional fall grazing.
	S.E. 13-37-5	G	Grazed hard 1910-30 and 1945-53.
	S.W. 18-37-4	G	Grazed hard 1910-30 and 1945-53.
	N.E. 34-37-5	U	Road allowance.
	"	G	Heavily grazed by dairy cattle and horses since 1942.
	N.W. 20-37-5	U	Never fenced. Some fall grazing previous to 1945.
	N.W. 1-37-5	U	Occasional fall grazing.
	N.E. 2-37-5	G	Heavily grazed until 1943, since then grazed by horses and cattle.
	E. 11-37-5	G	Grazed by cattle since 1946. Previously grazed by sheep.
b) fine textured	N.E. 23-36-4	U	Unfenced. Occasional fall and early spring grazing.
	W. 24-36-4	G	Continuously grazed for 40 years. Approximately 1 cow/8 acres.
	23-36-4	U	Wide headland, not fenced. Some fall grazing.
	"	G	Grazed for 40 years by horses and cattle.
	S.W. 23-36-4	G	Grazed 1895-1945 by cattle and horses. Since then grazed by horses.
	N.W. 19-37-5	G	Heavily grazed by cattle and horses since 1927.
Elstow	W. 9-37-6	U	Road allowance between sections 8 and 9.
	N.E. 17-37-6	G	Grazed by cattle and horses for 50 years.
	S.E. 27-37-6	U	Grazed previous to 1938. Since then not grazed.
	S.W. 25-37-6	G	Grazed since 1937 by horses and cattle.
	N. 11-37-6	U	Road allowance.
	S. 11-37-6	G	Heavily grazed until 1949, since then lightly grazed.
	N.E. 28-36-6	U	School yard.
	N.W. 27-36-6	G	Heavily grazed by cattle, 1 beast/1½ acres since 1944. Previously grazed by horses and cattle.

Appendix 2. Continued

Soil Association	Legal description (west 3rd meridian)	Grazed (G) or Ungrazed (U)	Management
Elstow (cont'd)	N.E. 23-36-5	G	Heavily grazed by horses and cattle until 1950. No grazing since then.
Biggar	N.E. 7-38-5	U	Not fenced. Occasionally cut for hay.
	S.E. 18-38-5	G	Grazed by horses for 40 years, by cattle since 1950.
	S.E. 32-38-5	U	Cut occasionally for hay.
	S.W. 33-38-5	G	Heavily grazed by dairy herd for over 30 years.
	S.W. 15-38-5	U	Road allowance.
	"	G	Grazed by cattle for 17 years at approximately 1 beast/6 acres. Before that it was ranged.
Asquith	✓ E. 16-36-5	U	City lots, unfenced.
	W. 15-36-5	G	Grazed for 25 years by horses and cattle.
	✓ S.E. 16-36-5	G	Fenced and grazed for 18 years. Cattle main stock. Heavily stocked prior to 1948.
	N.W. 14-36-5	G	A holding paddock near the farm. Heavily grazed and trampled.
	N.E. 15-36-5	G	Grazed by dairy cattle for 40 years. Usually 1 beast to 3-4 acres.
	S.W. 14-36-5	-	Part of pasture was ploughed 40 years ago and subsequently abandoned.
	W. 31-35-4	U	Settled 1906 and fall grazed since. Sometimes grazed in the spring. Fenced in with arable land.
	W. 7-36-4	U	Settled 1906 and fall grazed since. Fenced in with arable land. Little grazing since 1948.
Dune Sands	N.E. 30-35-5	U	Unfenced. Occasional fall grazing, but not since 1947.
	"	G	This was fenced from the above area in 1945 and has been severely grazed by horses since then.
	N.E. 34-35-6	U	Not grazed for 15 years except for occasional fall grazing.
	N.W. 35-35-6	G	Heavily grazed by cattle until 10 years ago, since then more leniently grazed.
	N. 7-35-5	U	Road allowance.
	N.E. 7-35-5	-	Pasture, part of which was arable in 1915 and subsequently abandoned. Grazed since 1932.

Appendix 3. Characteristics of soils of the study areas. Data obtained from soil profile examination. No mechanical analysis was done. The Munsell chart was used to determine the colour of the air-dry soil.

Soil Association	Legal description (west 3rd meridian)	Depth of sample (inches)	Texture	Colour	Colour chart number	Notes on profile
Weyburn						
a) coarse texture	W. 29-37-5	2	light-loam	v. dk. gray	10 Y.R. 3/1	Poor structure;
		9	sandy-clay-loam	grayish-brown	10 Y.R. 4/2	some coarse sand
		16	clay	grayish-brown	10 Y.R. 5/2	throughout profile
	N.E. 26-37-6	3	light-loam	v. dk. gray	10 Y.R. 3/1	Poor structure
		5	sandy-loam	grayish-brown	2.5 Y. 4/2	
		9	sandy-clay-loam	grayish-brown	10 Y.R. 4/2	
		16	clay-loam (hv)	pale brown	10 Y.R. 6/3	
	N.W. 7-37-5	6	light-loam	grayish-brown	10 Y.R. 5/2	Columnar structure
		12	sandy-clay-loam	pale brown	10 Y.R. 6/3	to 12 ins. $CaCO_3$
		20	clay	white	2.5 Y. 8/2	layer at 19 ins.
						Stony throughout.
	N.W. 7-37-4	2	light-loam	dk. gray	10 Y.R. 4/1	$CaCO_3$ layer at 12
		9	light-loam	grayish-brown	10 Y.R. 5/2	ins. Gravelly
		15	gravel hard-pan			throughout.
	N.E. 34-37-5	3	light-loam	dk. gray	10 Y.R. 4/1	$CaCO_3$ layer at 11
		10	gravel			ins.
		16	sandy-clay	lt. gray	2.5 Y. 7/2	
	N.W. 20-37-5	2	light-loam	dk. gray	10 Y.R. 4/1	$CaCO_3$ layer at 10
		6	sandy-clay-loam	grayish-brown	10 Y.R. 5/2	ins. Marked col-
		14	sandy-clay	lt. gray	2.5 Y. 7/2	umnar structure.
						Stony.
	N.W. 1-37-5	2	loam	v. dk. gray	2.5 Y. 3/1	Weak columnar
		4	loam	dk. gray	2.5 Y. 4/1	structure to 12 in.
		10	sandy-clay-loam	grayish-brown	10 Y.R. 4/2	$CaCO_3$ deposition 19
		16	clay-loam	grayish-brown	10 Y.R. 5/2	ins. Stony. Bands
		24	clay	lt. brown-gray	2.5 Y. 6/2	of gravel.
	E. 11-37-5	4	light-loam	gray	10 Y.R. 5/1	$CaCO_3$ layer at 13
		8	loam	grayish-brown	10 Y.R. 5/2	ins.
		18	sandy-clay	lt. gray	2.5 Y. 7/2	

Appendix 3. Continued

Soil Association	Legal description (west 3rd meridian)	Depth of sample (inches)	Texture	Colour	Colour chart number	Notes on profile
b) fine textured	N.E. 23-36-4	3	loam	dk. gray	10 Y.R. 4/1	$CaCO_3$ layer at 9 ins.
		8	loam	grayish-brown	2.5 Y. 5/2	
		16	sandy-clay	lt. brown-gray	2.5 Y. 6/2	
		22	clay	pale yellow	5 Y. 7/3	
	23-36-4	3	loam	grayish-brown	2.5 Y. 5/2	Stony.
		9	clay	pale brown	10 Y.R. 6/3	
	N.W. 19-37-5	3	loam	v. dk. gray	10 Y.R. 3/1	Columnar structure to 13 ins. $CaCO_3$ layer at 15 ins. Pavement of boulders at 15 ins.
		6	clay-loam	grayish-brown	10 Y.R. 5/2	
		12	clay-loam	pale brown	10 Y.R. 6/3	
		18	clay	lt. brown-gray	2.5 Y. 6/2	
Elstow	W. 9-37-6	2	loam	dk. gray	10 Y.R. 4/1	Columnar structure to 15 ins.
		6	clay-loam	dk. gray	10 Y.R. 4/1	
		15	sandy-clay-loam	v. dk. gray	10 Y.R. 3/1	
		20	clay	dk. gray	10 Y.R. 4/1	
	N.E. 17-37-6	2	light-loam	v. dk. gray	10 Y.R. 3/1	$CaCO_3$ layer at 11 ins.
		5	light-loam	dk. gray	10 Y.R. 4/1	
		10	loam	dk. gray	10 Y.R. 4/1	
		18	loam	grayish-brown	10 Y.R. 5/2	
		22	sandy-clay-loam	pale brown	10 Y.R. 6/3	
	S.E. 27-37-6	2	loam	pale olive	5 Y. 3/2	Columnar to 20 ins.
		6	sandy-clay-loam	grayish-brown	2.5 Y. 5/2	
		18	clay	pale olive	5 Y. 6/3	
		24	coarse sand	pale olive	5 Y. 6/3	
		36	silty-clay			
	S.W. 25-37-6	3	loam	v. dk. gray	10 Y.R. 3/1	Weak columnar to 10 ins. $CaCO_3$ layer at 15 ins. Parent material till. Profile approaches Oxbow type.
		6	clay-loam	brown	2.5 Y. 3/2	
		12	clay	grayish-brown	2.5 Y. 5/2	
		18	clay (hv)	lt. gray	2.5 Y. 7/2	

Appendix 3. Continued

Soil Association	Legal description (west 3rd meridian)	Depth of sample (inches)	Texture	Colour	Colour chart number	Notes on profile
	N. 11-37-6	2	clay-loam	v. dk. gray	10 Y.R. 3/1	Good topsoil structure. Solonetzic.
		5	clay-loam	dk. gray	10 Y.R. 4/1	
		12	silty-clay	gray	10 Y.R. 5/1	
		14	silty-clay	grayish-brown	10 Y.R. 5/2	
		16	silty-clay (hv)	grayish-brown	2.5 Y. 4/2	
	S. 11-37-6	3	clay-loam	dk. gray	10 Y.R. 4/1	Columnar structure to 20 ins. $CaCO_3$ layer at 9 ins.
		6	silty-clay	dk. gray	10 Y.R. 4/1	
		12	silty-clay (hv)	lt. brown-gray	2.5 Y. 6/2	
		24	silty-clay (hv)	lt. gray	2.5 Y. 7/2	Good aggregation.
	N.E. 28-36-6	3	loam	dk. gray-brown	10 Y.R. 3/2	Columnar structure to 16 ins.
		12	sandy-clay-loam	brown	10 Y.R. 5/3	
		18	sandy-clay-loam	lt. brown-gray	2.5 Y. 6/2	
		28	sandy-clay-loam	lt. brown-gray	2.5 Y. 6/2	
	N.E. 23-36-5	3	fine sandy-loam	dk. gray	10 Y.R. 4/1	Blocky, wide columnar structure. Profile approaches Asquith type.
		9	sandy-clay	brown	10 Y.R. 5/3	
		15	clay	lt. gray	2.5 Y. 7/2	
		24	silty-clay			
Biggar	N.E. 7-38-5	3	sandy-loam	v. dk. gray	10 Y.R. 3/1	7 ins. of soil overlying gravel.
		9	gravel			
	S.E. 32-38-5	2	gravelly-loam	dk. gray	10 Y.R. 4/1	9 ins. of soil overlying gravel.
		6	gravelly-loam	dk. gray	10 Y.R. 4/1	
		10	gravel	brown	10 Y.R. 5/3	
	S.W. 15-38-5	3	sandy-loam	v. dk. gray	10 Y.R. 3/1	
		6	gravelly-loam	dk. gray	10 Y.R. 4/1	
		12	gravel	dk. gray	10 Y.R. 4/1	
Asquith	E. 16-36-5	3	light-loam	dk. gray-brown	2.5 Y. 3/2	Weak columnar to 16 ins. $CaCO_3$ layer at 18 ins.
		8	sandy-clay-loam	grayish-brown	2.5 Y. 4/2	
		16	sandy-clay-loam	grayish-brown	2.5 Y. 5/2	
		22	silty-clay	lt. gray	2.5 Y. 7/2	

Appendix 3. Continued

Soil Association	Legal description (west 3rd meridian)	Depth of sample (inches)	Texture	Colour	Colour chart number	Notes on profile
	N.W. 14-36-5	4	sandy-loam	v. dk. gray	10 Y.R. 3/1	Wide columnar
		9	sandy-loam	v. dk. gray	10 Y.R. 3/1	structure. Little
		18	sandy-loam	dk. gray	10 Y.R. 4/1	aggregation in top-
		42	sandy-loam	lt. brown-gray	10 Y.R. 6/2	soil.
	W. 31-35-4	3	v. fine sandy-loam	grayish-brown	2.5 Y. 4/2	Wide soft column-
		9	fine sandy-loam	dk. gray-brown	2.5 Y. 3/2	ar. $CaCO_3$ layer
		15	fine sandy-loam	grayish-brown	10 Y.R. 4/2	at 16 ins.
		24	sandy-clay-loam	grayish-brown	10 Y.R. 5/2	
	W. 7-36-4	4	fine sandy-loam	v. dk. gray	10 Y.R. 3/1	Columnar to 15
		10	fine sandy-loam	grayish-brown	10 Y.R. 4/2	ins. $CaCO_3$ dep-
		16	fine sandy-loam	grayish-brown	2.5 Y. 5/2	osition at 17 ins.
		20	sandy-clay-loam	lt. gray	2.5 Y. 7/2	
Dune Sands	N.E. 30-35-5	3	sandy-loam	dk. gray-brown	2.5 Y. 3/2	
		9	sand	gray-brown	2.5 Y. 4/2	
		18	sand	gray-brown	2.5 Y. 5/2	
	N.E. 34-35-6	2	sandy-loam	grayish-brown	10 Y.R. 4/2	Some topsoil
		10	sand	grayish-brown	2.5 Y. 4/2	crumb structure.
		20	sand	grayish-brown	2.5 Y. 5/2	
	N. 7-35-5	3	sand	grayish-brown	2.5 Y. 5/2	
		9	sand	grayish-brown	2.5 Y. 5/2	
		24	sand	pale olive	5 Y. 6/3	

Appendix 4. Relative efficiency of samples of various sites in ascertaining basal cover by the point-transect method.

Soils	Management and location of site west 3rd meridian	No. of point projections recorded	PERCENTAGE BASAL COVER *Bouteloua gracilis*	*Koeleria cristata*	*Stipa spartea curtiseta*	Total grasses	Total sedges	Total forbs	Total vegetation
Weyburn Association	Grazed E11-37-5	1,400 1,000	2.79 2.50	0.14 0.10	0.79 0.90	3.86 3.70	2.00 2.20	21.86 22.60	27.71 28.50
	Difference		+0.29	+0.04	-0.11	+0.16	-0.20	-0.74	-0.79
	Grazed NW7-37-5	1,200 1,000	2.92 1.80	1.42 1.70	0.50 0.60	5.50 4.80	3.25 2.80	13.92 15.90	22.67 23.50
	Difference		+1.12	-0.28	-0.10	+0.70	+0.45	-1.98	-0.83
	Grazed SW18-37-4	1,400 1,250	1.36 0.56	0.57 0.64	1.07 0.80	3.71 2.80	3.07 3.28	27.57 28.96	34.36 35.04
	Difference		+0.80	-0.07	+0.27	+0.91	-0.21	-1.39	-0.68
	Grazed SE13-37-5	1,200 1,000	1.75 1.60	2.08 2.10	0.50 0.40	4.50 4.20	2.33 2.40	31.08 29.60	37.92 36.20
	Difference		+0.15	-0.17	+0.10	+0.30	-0.07	+1.48	+1.72
Asquith Association	Grazed SW14-36-5	1,200 1,000	0.17 0.10	1.00 1.00	1.50 1.40	4.00 3.90	3.50 3.70	22.00 18.40	29.50 26.00
	Difference		+0.07	0.00	+0.10	+0.10	-0.20	+3.60	+3.50
Biggar Association	Ungrazed NE7-38-5	1,250 1,000	- -	0.72 0.60	1.04 1.20	5.04 4.70	1.36 1.60	14.08 13.60	20.48 19.90
	Difference		-	+0.12	-0.16	+0.34	-0.24	+0.48	+0.58
	Grazed SE18-38-5	1,550 1,300	0.58 0.38	1.61 1.69	0.19 0.15	3.03 2.92	2.84 3.00	34.77 35.46	40.65 41.39
	Difference		+0.20	-0.08	+0.04	+0.11	-0.16	-0.69	-0.74
	Grazed SW-15-38-5	1,000 800	1.30 1.00	2.20 1.88	1.00 1.13	5.50 5.00	3.60 3.63	20.10 20.00	29.20 28.63
	Difference		+0.30	+0.33	-0.13	+0.50	-0.03	+0.10	+0.58

Appendix 5. Dry weights in grams of roots in 16 core samples from relict grassland on Asquith soils. The individual soil horizons were washed separately and the roots dried and weighed. Five weights, one for each of 5 soil horizons, were obtained from each core. The number of such samples that would be necessary to demonstrate a difference of 15 percent between grasses (P=0.05) is calculated using the method of Paterson (1939).

Species	Core No.	Soil horizons 0-2	2-6	6-12	12-18	18-24	Total 0-24
Bouteloua gracilis	1	1.39	0.80	0.73	0.37	0.33	3.62
	2	1.36	0.99	0.45	0.37	0.24	3.41
	3	1.35	1.60	0.64	0.32	0.26	4.17
	4	1.33	0.81	0.48	0.49	0.35	3.46
	5	0.95	1.37	1.00	0.52	0.28	4.12
	6	1.73	0.86	0.47	0.30	0.47	3.83
	7	2.05	0.86	0.62	0.24	0.19	3.96
	8	1.00	0.95	0.86	0.53	0.17	3.51
Stipa spartea curtiseta	9	1.58	0.74	0.42	0.39	0.19	3.32
	10	1.61	0.65	0.32	0.23	0.25	3.06
	11	2.79	0.59	0.48	0.24	0.38	4.48
	12	2.16	0.68	0.71	0.22	0.20	3.97
	13	1.60	0.85	0.42	0.36	0.17	3.40
	14	1.66	1.06	0.47	0.17	0.17	3.53
	15	1.77	0.62	0.50	0.27	0.60	3.76
	16	2.85	0.97	0.39	0.31	0.17	4.69

0- to 2-inch horizon

	S.S.	D.F.	M.S.	F.	5%
Total	4.408	15			
Grasses	1.476	1	1.476	7.049	4.6*
Error	2.932	14	.209		

Std. dev. = $\sqrt{.209}$ = .458
Mean = 1.700
Coefficient of variability = $\frac{\text{std. dev.}}{\text{mean}} \times 100$ = 27.0%

The table on page 256 of Paterson (1939) shows that to show a 15% difference (P=0.05) 23 to 31 samples would be necessary.

Total cores (0 to 24 inches)

	S.S.	D.F.	M.S.
Total	2.930	15	
Grasses	0.001	1	
Error	2.929	14	.209

Std. dev. = $\sqrt{.209}$ = .458
Mean = 3.768
Coefficient of variability = 12.15%

From Paterson's table 7 samples would be necessary to show a 15% difference (P=0.05).

Appendix 6. Mean dry weights (less ash weight) in grams of roots, from samples each of eight 2-inch diameter cores, obtained under five species on two soils. Both grazed and ungrazed grassland was sampled. The number of sites (replicates) from which samples were obtained is noted. The mean weights and their standard errors are shown. The weights for five soil horizons were separately obtained and have been expressed as a percentage of the weight for the total sample.*

Species	Soil horizon	ASQUITH SOILS Ungrazed	%	ASQUITH SOILS Grazed	%	ELSTOW SOILS Grazed	%
		4 sites		2 sites		1 site	
Stipa spartea curtiseta	0- 2	11.20 ± 1.00	44.4	8.15 ± 2.72	36.4	14.57	59.6
	2- 6	5.95 ± 0.60	23.6	6.08 ± 0.40	27.2	3.62	14.8
	6-12	4.19 ± 0.55	16.6	3.90 ± -	17.4	3.59	14.7
	12-18	2.34 ± 0.26	9.3	2.18 ± 0.16	9.7	1.74	7.1
	18-24	1.57 ± 0.15	6.2	2.06 ± 0.11	9.2	0.91	3.7
	0-24	25.25 ± 0.95	100.0	22.36 ± 3.26	100.0	24.43	100.0
		4 sites		2 sites		1 site	
Koeleria cristata	0- 2	11.20 ± 1.15	44.9	12.04 ± 2.84	48.6	14.04	57.0
	2- 6	6.38 ± 0.75	25.6	5.43 ± 0.17	21.9	4.81	19.5
	6-12	3.77 ± 1.89	15.1	3.78 ± 0.07	15.2	3.39	13.8
	12-18	2.25 ± 0.18	9.0	2.13 ± 0.11	8.6	1.37	5.6
	18-24	1.39 ± 0.09	5.6	1.42 ± 0.23	5.7	1.01	4.1
	0-24	24.97 ± 0.50	100.0	24.79 ± 2.91	100.0	24.62	100.0
		4 sites		4 sites		1 site	
Bouteloua gracilis	0- 2	11.53 ± 0.95	42.7	8.10 ± 0.28	32.0	11.86	48.1
	2- 6	7.06 ± 0.7	26.1	7.63 ± 0.47	30.1	6.79	27.5
	6-12	4.38 ± 0.49	16.2	4.91 ± 0.42	19.4	3.54	14.4
	12-18	2.68 ± 0.56	9.9	2.77 ± 0.18	10.9	1.36	5.5
	18-24	1.38 ± 0.20	5.1	1.92 ± 0.13	7.6	1.10	4.5
	0-24	27.02 ± 2.60	100.0	25.32 ± 1.23	100.0	24.65	100.0
		1 site		3 sites		1 site	
Carex stenophylla enervis	0- 2	11.75	39.7	6.34 ± 1.53	30.7	10.79	46.5
	2- 6	7.34	24.8	5.81 ± 0.20	28.1	6.16	26.6
	6-12	5.45	18.4	4.54 ± 0.71	22.0	3.00	12.9
	12-18	3.13	10.6	2.40 ± 0.64	11.6	1.92	8.3
	18-24	1.90	6.4	1.57 ± 0.33	7.6	1.33	5.7
	0-24	29.57	100.0	20.66 ± 0.49	100.0	23.20	100.0

Appendix 6. Continued

Species	Soil horizon	ASQUITH SOILS Ungrazed	%	Grazed	%	ELSTOW SOILS Grazed	%
		1 site		1 site		1 site	
Artemisia frigida	0- 2	17.42	49.9	19.13	61.1	16.36	53.1
	2- 6	8.23	23.6	3.99	12.8	6.30	20.4
	6-12	4.52	12.9	3.72	11.9	4.34	14.1
	12-18	2.77	7.9	2.15	6.9	2.48	8.0
	18-24	1.99	5.7	2.30	7.4	1.33	4.3
	0-24	34.93	100.0	31.29	100.0	30.81	100.0

* To convert grams to lbs./acre multiply by 4401.2

Appendix 7. Mean dry weight (less ash weight) in grams of roots from samples each of eight 2-inch diameter cores 2 inches deep taken beneath *Bouteloua gracilis*. Samples were taken on grazed and ungrazed grassland on Asquith soils at each of four locations.

Site	Soil horizon		Ungrazed		Grazed
1	0 - 2		11.08		7.67
2	0 - 2		11.75		8.50
3	0 - 2		13.91		7.58
4	0 - 2		9.37		8.63
		Total	46.11	Total	32.38
		Mean	11.53	Mean	8.10
		Std. dev.	3.53	Std. dev.	0.30

Error difference = .958

t = 3.54

The result is significant at the P = 0.02 level.